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Journal
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Vol. 225 MAY, 1938 No. 5

MACHINE TOOLS IN AMERICA.*

BY

JOSEPH W. ROE, M.E.,

Visiting Professor of Management, Yale University.

While the Declaration of Independence was being signed in Philadelphia another revolution was already well under way in England, one so far-reaching in its effects that it has altered the economic life of the whole world. The Industrial Revolution was ushering in the Machine Age. But the Machine Age did not and could not come until men developed machines to make machinery with; i.e., machine tools. The facilities for working metals in 1776 were little better than those of the Middle Ages, the hammer, chisel and file to supplement casting and hand forging. All the structural parts of the newly invented engines and textile machinery were made of wood. Only the fastenings and smaller parts were of metal fitted by hand.

In the closing years of the 18th century Henry Maudslay, in London, laid the foundations of modern metal working tools by developing the slide rest, lead screw and change gears characteristics of all machine tools. Within a single generation, say by 1840, England had developed the engine lathe, planer, shaper and boring mill and had established a

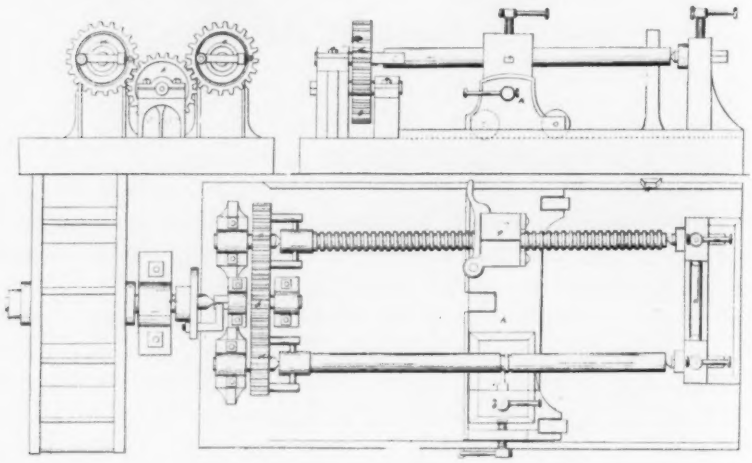
* Presented at a meeting held Thursday, December 2, 1937.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

world leadership in the machine tool field, which she maintained for many years.

Following her Colonial policy, England continued after the Revolution to prohibit the export of all machinery and the emigration of her mechanics. America, however, had declared an economic as well as a political independence and she began building her own machinery.

In 1789, the year of the adoption of the Constitution, Samuel Slater, a skilled English mechanic who had eluded the embargo on mechanics, reproduced the Arkwright spinning

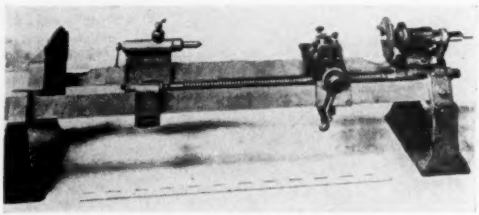


Wilkinson's Screw Threading Machine, 1797–8.

machinery at Pawtucket, Rhode Island, and started the American cotton industry. Sylvanus Brown, who helped Slater in this work, is said to have invented a lathe for cutting screws for sperm oil presses, but all records of it seem to have been lost. David Wilkinson, Slater's brother-in-law, at North Providence, R. I., now Pawtucket, invented a screw cutting lathe in 1797 and patented it on December 14, 1798. This machine is of unique interest. So far as I know, no printed description of it exists but I have recently obtained a photostat copy of the original manuscript specification. A drawing of it was made by the Patent Office in 1845.

This lathe was 18 or 20 feet long and driven directly by

a water wheel. It had a headstock, and adjustable tail stock, a tool-carrying slide mounted on 3 rollers and running between 2 guiding surfaces at the sides. The tool slide was adjustable for depth of cut and received its axial motion from a lead-screw through a clamp-nut arranged to throw out automatically at the end of the cut. The patent describes and the drawing shows the method of cutting both a screw and its corresponding nut. This tool contains all the essential elements of Maudslay's first lathe, now in the South Kensington Museum, which was built about 1797. In both of these lathes the lead-screw and the work seem to have been driven in one-to-one ratio. If so, to cut screws of different pitch, different lead screws had to be used.



Maudslay's Lathe. About 1797.

Both Wilkinson's and Maudslay's lead-screws could have been used for cutting various pitches by changing the lead-screws, and Wilkinson says in his specification that he could cut a "screw of any size or any number of threads wished for." He does not state whether he did this by changing the gears or by changing the lead-screw but the construction shown in the drawing would seem to indicate that it was by changing the lead-screws. Maudslay was definitely doing it by means of change gears in 1800.

This seems a clear case of the independent and simultaneous development of a great invention, as the two machines were built apparently in the same year and, with communications as they were then, it is unthinkable that either of these two men, one in London, the other in a little town in Rhode Island, knew of the other's work. We owe the greater debt to Maudslay because of his greater influence and because of the certainty of his use of change gears three years later, and

because the design of his slide rest was better. It does show however that the American mechanics from the beginning were not merely copying English practice.

The Wilkinson patent ran out before the lathe came into general use in this country. But 50 years later, in 1848, he was voted $10,000 by Congress "for benefits accruing to the public service for the use of the principle of the gage and sliding lathe, of which he was the inventor."

Wilkinson, by the way, was one of the ten or more inventors of the steamboat. He built one in 1794, and ran it from Winsor's Cove to Providence. This was years before Fulton, but not so early as John Fitch, who carried the invention much further here on the Delaware River in the 1780's.

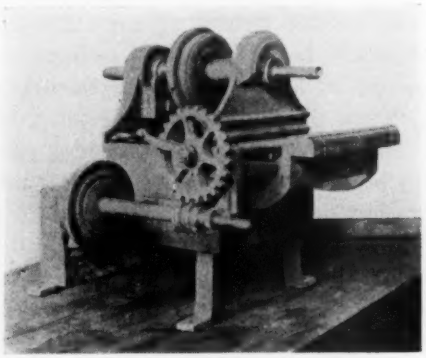
About 1800 Eli Whitney and Simeon North began the interchangeable manufacture of firearms in Connecticut, with a far-reaching influence on tool building which led to the development of entirely new types of tools. This will be referred to later.

By 1815 there were 140 cotton manufactories within 30 miles of Providence. From there they spread northward. In 1822 Slater and other Rhode Island men started the Amoskeag mills at Manchester, N. H., which later became the greatest textile mill in the world. Its original charter was very broad and for years they operated a large machine shop where they built locomotives, engines, textile machinery and machine tools. About the same time the mills at Lowell and Lawrence were started and they too operated large machine shops. One of the men who worked in both the Amoskeag and Lowell shops was William Bement.

In 1824 Ira Gay, another R. I. man, founded what later became Gay, Silver and Co. near Lowell, which manufactured textile machinery and machine tools. This shop is in the apostolic succession of those who developed the milling machine out of the simple affair Eli Whitney was using in New Haven. Frederick W. Howe, who learned his trade here, took the beginnings of the turret lathe to Windsor, Vermont, where Robbins and Lawrence made a modern machine out of it. This old Gay-Silver shop continued until well into this century, a veritable museum of old machine

tools, stone bed planers, milling machines, etc., which were nearly a century old when they were dismantled. From 1820 to 1840 other shops sprang up in the Merrimac Valley. They were primarily building textile machinery, but showed little specialization. They built anything they could sell. The Gage, Warner and Whitney shop, at Nashua, is claimed to have been the first one in the country devoted exclusively to the production of machine tools, but it seems never to have been a very large one.

By 1840 or so Worcester emerges as the leader in the production of machine tools. There had been small shops



Eli Whitney's Milling Machine. About 1818.

there as early as 1810. In one of these Thomas Blanchard invented his lathe for turning irregular forms, which was set to turn gun stocks in the Springfield Armory in 1818. The Blackstone Canal between Providence and Worcester, which was opened in 1828, and the Boston and Worcester Railroad, opened in 1835, developed a wide market for the city.

"Uncle Sammy Flagg" was the first man in Worcester to center entirely on tool building. His first lathes had wooden beds, wrought iron strips for ways, chain operated carriage, and cast gears. Among the early tool builders in Worcester was Lucius W. Pond, who started the chain of firms which has become the Niles-Bement-Pond Company; J. A. Fay, who started the present J. A. Fay and Egan Co. of Cincinnati; Whitcomb, Prentice, Blaisdell and Reed, names familiar to all the older men here this evening.

An element in this growth was the excellent facilities Worcester offered for starting business in a small way. Nearly all these enterprises began as tenants in one of the large buildings which rented space and power. One of them, Merrifield's, was 3 stories high, 1100 feet long and had 50 tenants employing from 2 to 800 men. Perhaps this situation has some suggestion for us today. The Bush Terminal in New York is a modern counterpart.

There were of course other centers; the Putnams in Fitchburg, Flather in Nashua, and Baxter D. Whitney at Winehenden were all well known. The last died in 1915, 98 years old, the last of the early generation of mechanics.

Machine tools in this country were called into existence to supply the needs of three groups of industries: The general purpose tools such as lathes, planers, boring mills, drilling machines, etc., were developed by the textile industry and the railways. All the early tool builders we have so far considered were building this type. Their tools were of the same general design as those being built in England at that time, no better and probably not so good.

High production tools such as turret lathes, milling machines, precision grinders, etc., were developed by or for the gun makers, clock makers, and later the manufacturers of sewing machines, bicycles, typewriters, automobiles and other interchangeable products. These were developed later than the other group, slowly at first, but rapidly after 1850. Their production centered in Hartford, Windsor, Vt., and Providence, and the names of Eli Whitney, E. K. Root, Frederick W. Howe, R. S. Lawrence and C. M. Spencer, J. R. Brown, and Pratt and Whitney will always be associated with them. Their work has made possible the interchangeable system of manufacture which is America's great contribution to modern industry.

All these men worked in New England. With the westward spread of industry which came with the development of railroads, machine tool building began a migration also. Philadelphia, in early years the largest city in the country, inevitably attracted mechanics. Oliver Evans who worked here was a great mechanic; just how great we can realize

from Mr. Bathe's fine life of him recently published. He left a deep impression on engine building and was the father of modern materials handling, but his work was not in the field of tool building. One of the Rhode Island Jenks, who served his time with Samuel Slater, started the textile industry in Pennsylvania in 1810, and by 1825 there were 30 textile mills in and about Philadelphia. Wood, Hendel, Smith and Uhlinger were early builders of textile machinery. Matthew Baldwin began making book binder's tools, presses, rolls, steam engines, and finally in the early 1830's, locomotives. In 1836 the Southwark Foundry was started and they were the ones who introduced the steam hammer into the U. S. under an arrangement with James Nasmyth.

The two men however who made Philadelphia a great tool building center were William Sellers and William Bement. Sellers was born in Pennsylvania, apprenticed to his uncle, John Poole, in Wilmington, and when only 21 he invaded New England and became foreman of a shop in Providence. Three years later he moved to Philadelphia, with Edward Bancroft of Providence, and started the firm of Bancroft and Sellers which has become the William Sellers and Co. of today. At first Bancroft was the inventor and Sellers the executive. Sellers's designing ability did not develop until after Bancroft died in 1855. The first of his 90 or more patents was granted in 1857. These covered machine tools of all kinds—injectors, cranes, hammers, etc. His influence here on tool building paralleled that of Whitworth in England in an amazing way. Like Whitworth he discarded ornamentation in tools, painted them machine gray and made them much heavier. He adopted standards and adhered to them so closely that repair parts can be supplied for tools made 50 years before. Like Whitworth also he established a system of screw threads which became a national standard. It was first proposed in a paper read before this Institute. A committee was appointed to investigate the problem and recommend a standard. On this committee were William Bement, C. T. Perry, S. V. Merrick, J. H. Towne, and Coleman Sellers. They recommended the system proposed by William Sellers. It was adopted by the U. S. Government in 1868, the Pennsylvania R. R. in 1869, the Master Car Builders Association in 1872,

and has become the standard for the whole country. Sellers was notable for his heavy machinery. One of his lathes weighed 500,000 pounds. His tools for handling large ordnance and armor plate have attracted world wide attention. He gave Frederick W. Taylor his opportunity and backed him in the long and costly experiments on the Art of Cutting Metals and the work which inaugurated modern scientific management.

William Sellers and Co. has had another master tool builder in Coleman Sellers, a cousin of William Sellers. Born in Philadelphia, he too became a superintendent at 21, in this case in Cincinnati, where he was with the Globe Rolling Mill and the Niles Company which later moved to Hamilton. In 1857 he returned to Philadelphia and was chief engineer of William Sellers and Co. for 30 years. While his work, like that of Wm. Sellers, covered a wide range of tools, he is best known in the field of railway tools and equipment. He was a charter member and president of the A. S. M. E., well known abroad, and served on the Commission which determined the type of turbines and generators used in the first power development at Niagara Falls.

William Bement was born in New Hampshire in 1817. He served his apprenticeship in a textile machinery shop, and in 1840 went to Manchester as foreman and contractor in the Amoskeag shop. From there he went West and had interesting experiences in pioneer tool building where he had to fall back on hand work to build them as there were no planers within hundreds of miles. He was burned out twice, came back East, and spent 6 years with the Lowell machine shop. He moved to Philadelphia in 1851 and started the manufacture of machine tools with E. D. Marshall and Colby. Their entire machine shop was 40 by 90 feet, with a 12-foot room for an office. The plant, known as "Industrial Works," grew rapidly and at one time was the largest in the country devoted to tool building. Like Sellers Bement held to work of the highest quality, and their tools were much heavier than those of the New England builders, with whom they were competing, with the result that Worcester gradually lost its leadership in the tool building field.

Others who have had a part in the career of this great

company were Dougherty, Clarence and William Bement, and F. B. Miles. The last, a workman at Bement's, started his own tool manufacturing business where he greatly improved the steam hammer. In 1885 his works consolidated with Bement and Sons and became the firm of Bement, Miles and Co. In 1900 this business became part of the Niles-Bement-Pond Co.

By 1880 other centers were beginning to compete with the New England tool builders. In 1881 Worcester R. Warner and Ambrose Swasey left Pratt and Whitney at Hartford, where both of them had been contractors, and went to Chicago for one year, and then to Cleveland, where they founded the firm of Warner and Swasey, which built various types of tools, centering finally on hand operated turret lathes which have won world wide recognition. Because of their avocation of astronomy, Mr. Warner and Mr. Swasey have turned their mechanical skill to the building of telescope mountings and their firm is probably the most famous maker of these most accurate and delicate of all mechanisms.

Kempsmith, Lucas, Bardons and Oliver, all well known tool builders, worked at some time with Warner and Swasey. In 1895 A. C. Henn and Reinhold Hackewessel, two mechanics in Hartford, invented the automatic multi-spindle turret lathe. Seven years later they moved to Cleveland to form, with others, the National Acme Co. Cleveland has become and remains a leader in high grade tool manufacture.

It is claimed that Cincinnati is the largest tool building center in the world. There are approximately 40 firms there in this industry, many of them large and well known. This development is interesting. Seventy-five years ago Cincinnati did most of the engine building and repair work for steamboats in the Mississippi and Ohio Valleys. When the river traffic disappeared before railroad competition the mechanics engaged in this work had to turn to something else. The first to enter into tool building was "Old John Steptoe," a picturesque figure whose name came, it was said, from his having been left as a foundling on a doorstep. Protected by the high freight rates from the east, he began to make a cheap copy of the Putnam lathe. From this he went on to other tools and built up a business which employed at

times 300 men. Among them were many who later became well known tool builders. And among these was Wm. Lodge, an Englishman who had come to Cincinnati in 1872. In 1880 he and Wm. Barker started in business with $1000 of their savings as capital. They rented a basement, bought a few second hand tools, fitted them up to do proper work, went out and secured some business, came back and executed it, and then delivered it, all by themselves. The business inventoried $8000 at the end of the first year, $32,000 at the end of the second year, and $400,000 at the end of ten years. Fifteen months after starting, they employed 75 men. Lodge was well known among the mechanics and had been president of their union. If he could do this, why couldn't someone else? A number of the best known of the Cincinnati tool building firms were started because of this example.

The policy of Mr. Lodge's firm hastened this result. In 1886 the firm had become Lodge and Davis. Lodge was a mechanic and wanted to specialize on lathes. Davis was a business man and wanted to have a complete line of tools because of the selling advantage. The controversy nearly broke up the partnership, but resulted in a policy which could not have been better designed to build up a great tool building center. They concentrated on the *manufacture* of lathes, but *marketed* other types of tools, placing orders with mechanics known to them who were just starting up, or with workmen or foremen in their own plant whom they helped to set up in business. For example, to Smith and Mills, who had been foremen with Steptoe, they gave an order for 300 shapers, and another one to Smith and Silk; to R. K. LeBlond an order for slide rests; to Wm. Owens, one of their own workmen, one for Fox Monitors. Owens went in partnership with Montanus and the Lodge firm bought their entire product for 8 years. All of these orders were contingent upon their keeping away from lathes.

Besides these and others who worked with Lodge there were such men as Bickford, Norris, Holtz, Geier, who have had a leading part in the building up of the industry in Cincinnati. The Niles Co. moved to nearby Hamilton about 1876, specializing on heavy tools and cranes, and is now part

of the Niles-Bement-Pond Co. George Gray, later builder of planers, was their designer and superintendent.

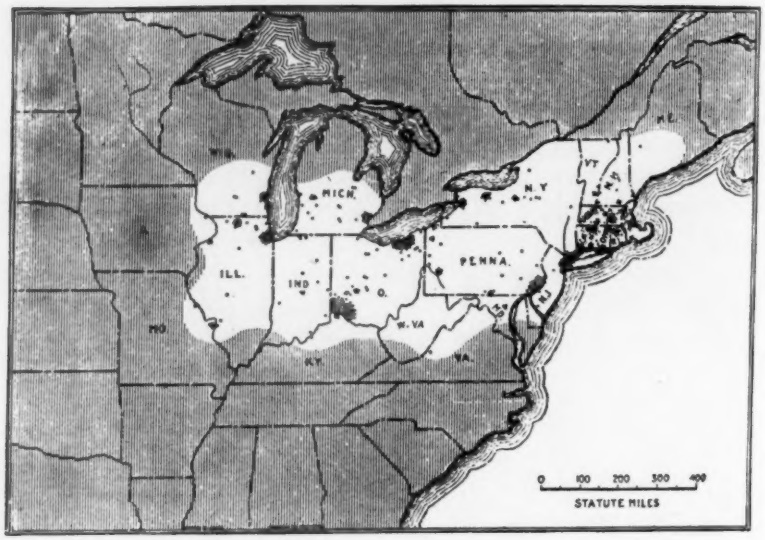
Indianapolis, Rockford, Madison and Milwaukee have also become centers of tool building but it is impossible to go into their history within the limits of this paper.

We have been considering American tool building by geographical distribution. Another way would be by types and their inventors or developers. The essentials of the engine lathe, planer, drilling machine, shaper, steam hammer, and boring mill are English, and the chief inventors connected with them are Maudslay, Roberts, Nasmyth, Whitworth, Clement and Bodmer. The machines which we owe to American mechanics are the milling machine, in its various forms for mass production, to Eli Whitney, F. W. Howe, and Robbins and Lawrence; the universal milling machine, for tool room use, chiefly to Joseph R. Brown; the hand operated turret lathe to Howe, Stone, Hartness, Warner and Swasey, and others; the automatic turret to C. M. Spencer; the multiple spindle automatics to Henn and Hackewessel, Gridley and E. P. Bullard; precision grinding machines to Norton, Landis, Heald, and Brown and Sharpe; broaching to J. N. LaPointe; gear-cutting machinery to Brown and Sharpe, Gleason, and Fellows; boring mills to Bement, Sellers, Niles and Bullard; scales and micrometers and measuring devices to Brown and Sharpe, S. J. Darling and Pratt and Whitney.

Please understand that this list is not inclusive. Many men and firms have had a part in the development of these tools; the names given are only those which occur in a rapid survey of the field. Some men like E. K. Root and Sellers have contributed to so many types of tools their names are not associated with any particular one, and others too numerous to mention here have by their combined work greatly improved the various tools, adding to their strength, accuracy and efficiency. Concurrent with all of this has been a steady refinement in methods of measurement and gaging. This has been a vital element, for no art or science can be more refined than its methods of measurement.

A good mechanic of 75 years ago, if turned loose in such an exhibition as that recently held by the Machine Tool Builders Association in Cleveland where all the latest tools

were in operation, would be dazed. Gone is the maze of shafts and belting and all the belt shifters. Speeds have gone up. Unbelievable cuts would be tearing off blue chips with red hot cutting tools. The machines would be feeding themselves, starting and stopping, and changing cuts automatically. Many of the processes such as milling, grinding, welding, broaching and gear cutting which he would see would be developed beyond all recognition, or wholly new.



Location of the American Tool Building Industry.

The cutting edges of the tools would be of materials he never knew; many feeds hydraulic, and controls pneumatic, and the machines would be driven by a force which he has heard of, it is true, but which he associates only with Benjamin Franklin and the magnetic telegraph.

For the first half of the last century American machine tool builders were pioneering, producing tools only along with other machinery. By 1850 there was a recognized tool building industry which was developing entirely new types of tools for interchangeable manufacture and mass production. There has been a steady growth ever since. The value of

the tools produced in the U. S. in 1850 has been estimated at $6,000,000. In 1900 it had risen to approximately $50,000,000. Today there are about 250 firms, employing 60,000 men. The total value of the tools produced is about $200,000,000 per year, of which $50,000,000 or 25 per cent represents exports, going chiefly to the most highly industrialized countries.

The American tool building industry began with the independence of this country, and has kept pace with the needs of its growing industries. To a degree unrealized by the general public it has been a major factor in that growth and today has world leadership in its field.

Propane to Power Railway Coach Air Conditioning Compressors.—C. G. CALLOW. (*Gas*, Vol. XIV, No. 2.) With the goal of eliminating from locomotive power, the power necessary for driving air conditioning equipment, thereby resulting in the possibility of a greater number of cars being handled at higher speed, the engineers of the Waukesha Motor Co. developed a mechanical compression system known as the Waukesha Ice-Engine. The unit designed is independently powered with a fully automatic internal combustion engine using propane as fuel, is compact, reliable, quiet, economical, and renders service regardless of car location, train movement or stand-by service. Some of the advantages of this fuel are: one hundred pounds of propane is the equivalent of 10,000 lbs. of ice for air conditioning and a standard three-tank supply is enough for a run from Chicago to the Pacific Coast, and it has an octane rating of 125, permitting compression ratios as high as 10 to 1. The fuel is delivered to the engine as a dry gas, which reduces crankcase dilution and carbon deposits to a minimum. In developing this system the rules of the Interstate Commerce Commission, the Bureau of Explosives, and the Fire Underwriters Laboratories were adhered to. Having developed this independently powered air conditioning unit, the service was then extended to the use of the internal combustion engine for supplying a constant source of electrical energy to passenger cars without imposing any power load on the locomotive. This operates on the same approved propane fuel system. If a car is equipped with both the ice-engine and the engine generator units, both may be operated from a single fuel system, or each independently, as desired. In addition to these services the fuel is also being extensively used on some railway systems for cooking in dining, buffet, and snack car service as well as for refrigeration in dining and club cars.

R. H. O.

PHOTOELASTIC ANALYSIS OF STRESS CONCENTRATION FOR BEAMS IN PURE BENDING WITH A CENTRAL HOLE.

BY

JAMES J. RYAN AND LEANDER J. FISCHER,

Mechanical Engineering Department,
University of Minnesota.

SYNOPSIS.

This paper presents a photoelastic study of the conditions of stress concentration about a hole in a beam subjected to pure bending. Rules for stress determination in beams of this type are suggested.

INTRODUCTION.

Localized stress concentrations at holes, notches and abrupt changes of section may set up maximum stresses which exceed (1) the elastic limit of the material producing permanent set for static loads, or (2) the endurance limit for dynamic conditions resulting in fatigue failure. Correct evaluation of these concentrations is of great practical importance in the design of machines.

The effects of holes and notches in bars subjected to tension, and the stress distribution around a reëntrant corner under combined bending and tension were first investigated experimentally by E. Preuss [1] in 1912, who used a very sensitive extensometer to measure the strain between adjacent points on the edges of steel specimens.

More recently the development of the photoelastic method of stress analysis has made possible a comprehensive study of stress concentrations for a large number of practical cases. This method is particularly useful since at the free boundary of a hole, notch or fillet the maximum stress is directly obtainable from the isochromatic photograph.

Wahl and Beeuwkes,[2] and Frocht,[3] have continued the

[1] Preuss, E., *V. D. I.*, **56**, 1349 (1912); **57**, 664 (1913).

[2] Wahl, A. M. and Beeuwkes, R. Jr., *Trans. A. S. M. E.*, **56**, No 8, 617 (1934).

[3] Frocht, M. M., *Journal of Applied Mechanics, A. S. M. E.*, **2**, No. 2, A67 (1935).

work begun by Coker and Filon [4] on the effects of holes and fillets in bars under tension and compression, while Weibel [5] has made a study of reëntrant corners at an abrupt change in section under tension, compression and bending.

The problem of the stress concentration produced by a hole centrally located in a beam with uniform bending was considered by Tuzi [6] in 1928 who suggested an approximate mathematical solution in which the depth of the beam was considered to be infinite. He also made a photoelastic study of the stress distribution in beams with holes of various diameters up to .6 of the depth of the beam.

Later Howland and Stevenson [7] developed an exact solution for this problem in the form of a bi-harmonic function. Unfortunately this function does not converge rapidly enough to give an accurate solution when the diameter of the hole exceeds .5 of the depth of the beam.

The purpose of this work was to continue by photoelastic analysis the investigation of stress concentration for beams in pure bending with a central hole.

I. TEST PROCEDURE.

The polariscope used in the analysis of this problem was developed for general photoelastic application in the Machine Design Laboratory of the University of Minnesota Institute of Technology. The design [8] follows the conventional transmission type of prism polarizer, but is unusual in detail and size, having a 7 inch diameter light field. Figures 1 and 2 are photographs of the polarizer and analyser sections of the polariscope.

The beam models were set up in the stressing frame shown in Fig. 1, and subjected to a uniform bending moment applied

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[4] Corker, E. G. and Filon, L. N. G., "Photo-Elasticity," Cambridge University Press, 1931, pp. 470–497.

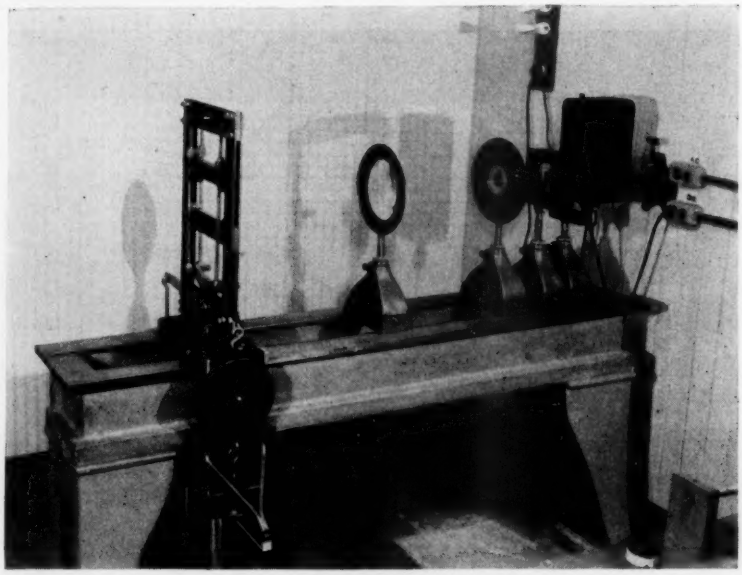
[5] Weibel, E. E., *Trans. A. S. M. E.*, **56**, No. 8, 637 (1934).

[6] Tuzi, E., *Scientific Papers of the Inst. of Physical and Chemical Research*, **9**, No. 156, 65 (1928).

[7] Howland, R. C. J. and Stevenson, A. C., *Phil. Trans. Royal Soc. London*, A. **232**, 155 (1933).

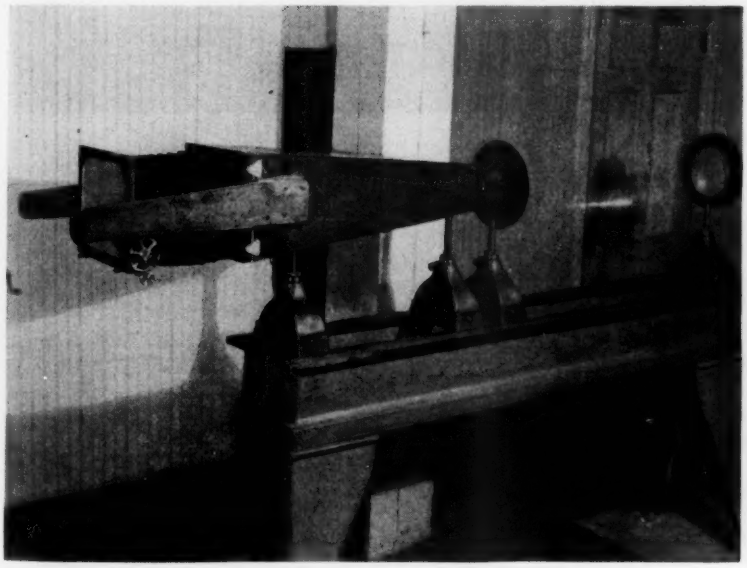
[8] Ryan, J. J., JOURNAL OF THE FRANKLIN INSTITUTE, **233**, No. 6, 715 (June, 1937).

FIG. 1.



Polarizer section of polariscope.

FIG. 2.



Analyzer section of polariscope.

FIG. 3.

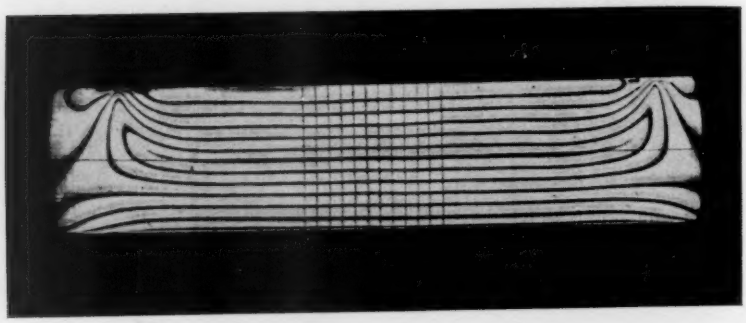


FIG. 4.

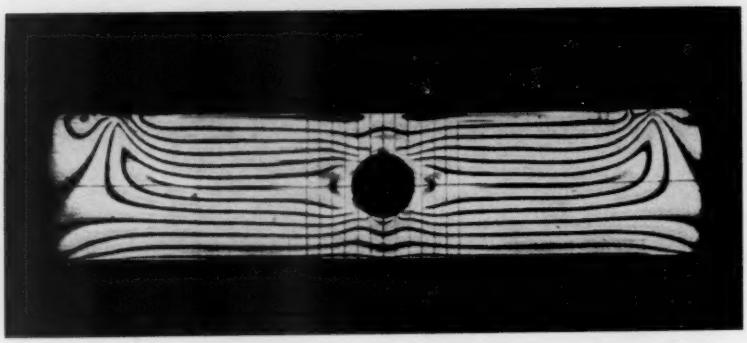
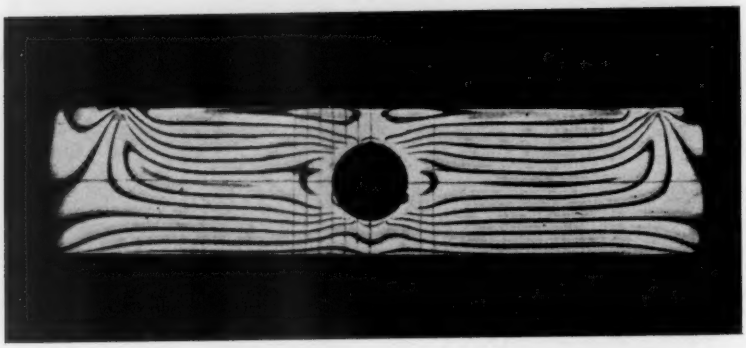


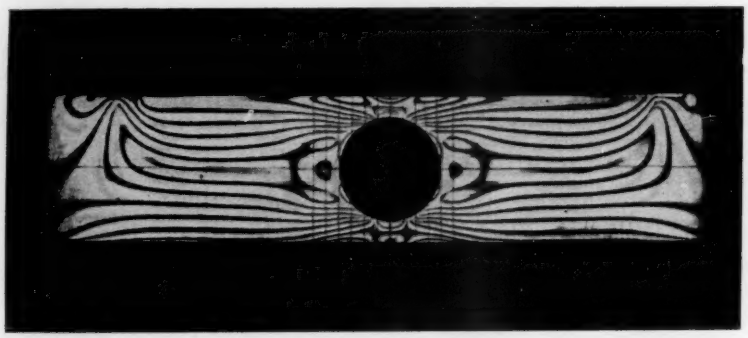
FIG. 5.



by vertical loads on the ends. Hardened steel plates 3/64 inch in thickness and 5/8 inch in length, with carefully honed surfaces, were placed between the supports and the model to avoid the formation of a uniform tension along the axis of the beam with large deflections.

The Bakelite material after annealing was found to have a uniform residual stress of about a fourth of a fringe, which was removed from the test results by averaging. The beams were first calibrated in pure bending for a series of loads to determine the fringe orders at the outer edge. As the holes were bored for the stress concentration tests, the highest of these loads that would give a maximum value of stress under the elastic

FIG. 6.



limit was used. The tests were made immediately after the holes were machined, and the isochromatic stress photographs were taken with a time lapse of two minutes following the application of the load.

Data for tests on two beams of different depths were obtained and are discussed as Series 18 and Series 19. Isochromatics of the beam without a hole in the Series 18 tests are shown in Fig. 3. In Figs. 4 and 5, the beam is shown with the stress distribution on either side of the condition where the diameter of the hole is one-half the depth of the beam. The stress condition for the largest hole considered in this series is pictured in Fig. 6. The beam in the Series 19 tests is shown with a small hole in Fig. 7, while Figs. 8 and 9 span the case where b/h is equal to one-half. Figure 10 compares with

FIG. 7.

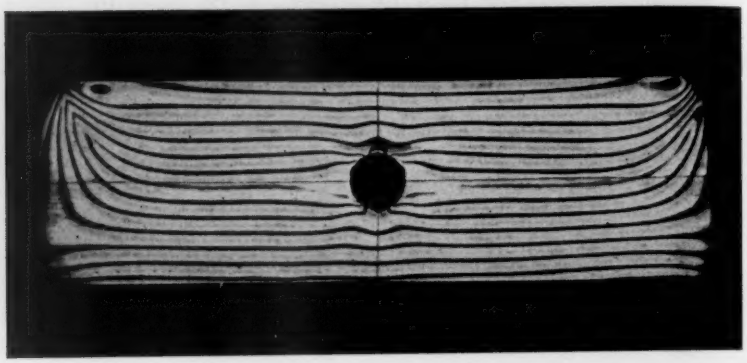


FIG. 8.

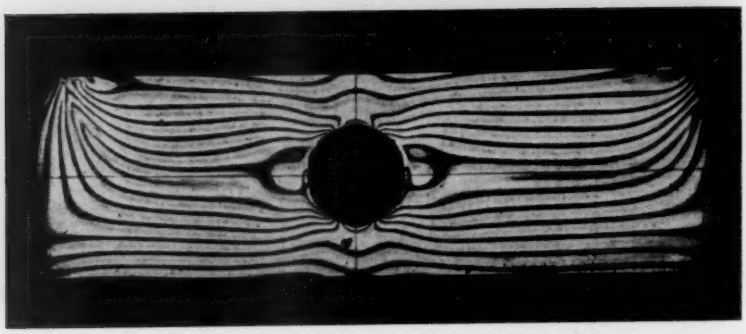


FIG. 9.

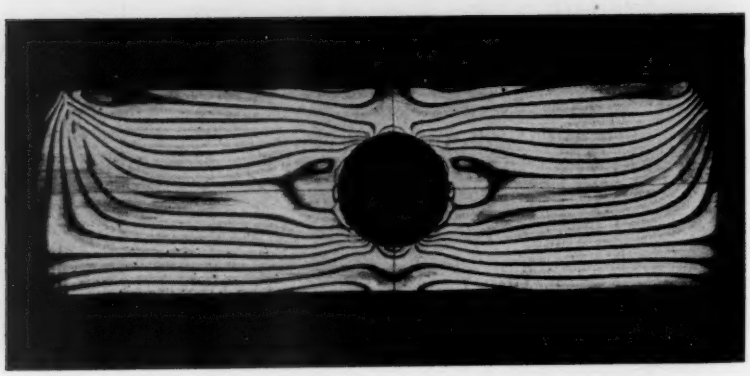


FIG 10.

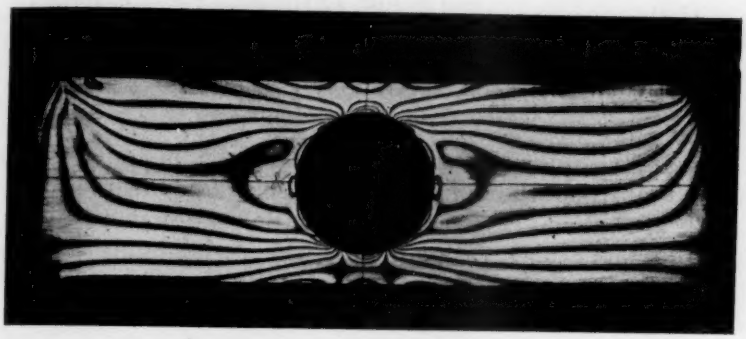


FIG. 11.

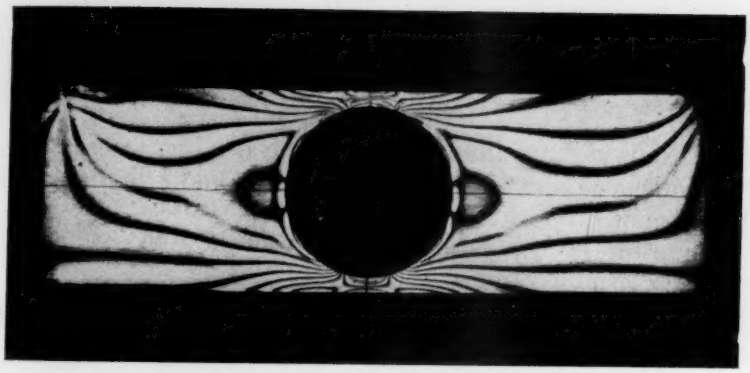


FIG. 12.

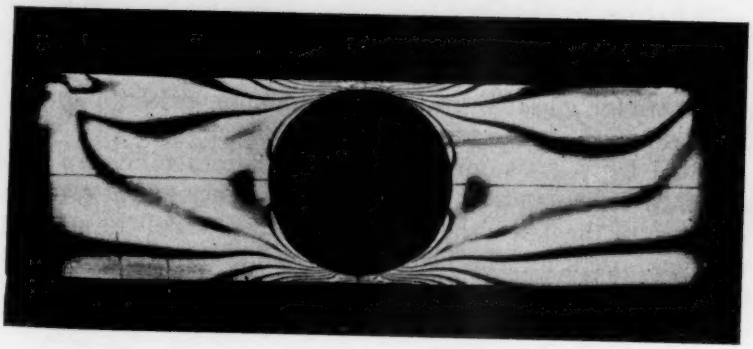


Fig. 6 of Series 18. The maximum hole in the beam is approached in Fig. 11, and in Fig. 12 the final ratio of diameter of hole to depth of beam is 0.907.

II. INTERPRETATION OF RESULTS.

A. The Stress Concentration Factor in Bending.

As the ultimate object of this research is to obtain a method by which the limiting stress in machine members may easily be evaluated, the results have been presented in the form of stress concentration factors which when multiplied by the maximum stress obtained from the usual methods of analysis give the maximum value of the stress produced by the hole.

The maximum value of the stress occurring at the outer edge of an unperforated rectangular beam (of unit thickness) in pure bending is given by the equation (*a*),

$$S_m = \frac{6M}{h^2}, \qquad (a)$$

where S_m is the maximum value of the bending stress, M is the bending moment applied to the beam, and h is the depth of the beam.

The stress concentration factor K from the above definition will be determined by

$$K = \frac{S_c}{S_m}, \qquad (b)$$

where S_c is the maximum value of the concentrated stress produced by the hole.

As S_c may be obtained from the test photographs in terms of fringe orders, and S_m is also given in terms of fringe orders by the calibration photographs of the same bending moment, the factors for various ratios of the diameter of the hole b to the depth of the beam h are easily calculated.

Table I gives a summary of the test data taken for two beams, Series 18 and Series 19, with reference to the various diameters of the holes, the ratios b/h, the values of the stresses in fringe orders for the beam calibration, the concentration stress in fringe orders at the edge of the hole and the outer edge of the beam at the centerline of the hole, and the re-

TABLE I.

Beam Data, Fringe Orders and Concentration Factors.

Test Series		Fig. No.	Diam. of Hole b	Ratio b/h	Fringe Orders S_e		Concentration Factors			
							K		K'	
					At Edge of Hole	At Edge of Beam	At Edge of Hole	At Edge of Beam	At Edge of Hole	At Edge of Beam
Depth of Beam h = 1.428"	18 C	3	0		(S_m)	6.33				
	D		.0625	.044	.4	6.2	.063	.98	.0945	1.47
	E		.125	.088	1.0	6.2	.16	.98	.24	1.46
	F		.250	.175	2.2	6.4	.35	1.01	.51	1.48
	G		.375	.263	3.3	6.4	.52	1.01	.73	1.42
	H		.500	.350	4.4	6.4	.695	1.01	.92	1.34
	I	4	.625	.437	5.6	6.3	.885	0.995	1.08	1.21
	J	5	.750	.525	7.4	6.2	1.17	.98	1.27	1.07
	K		.875	.613	10.0	6.0	1.58	.95	1.48	.888
	L	6	1.000	.700	12.6	5.7	2.00	.90	1.53	.69
Depth of Beam h = 1.791"	19 D		0		(S_m)	6.75				
	F	7	.500	.279	3.6	6.6	.533	.98	.73	1.35
	G		.750	.418	5.6	6.9	.83	1.02	1.03	1.27
	H	8	.875	.488	7.0	7.0	1.04	1.04	1.19	1.19
	I	9	1.000	.557	9.0	6.8	1.33	1.01	1.38	1.05
	J		1.125	.627	11.2	6.6	1.66	.98	1.51	.892
	C		0		(S_m)	5.00				
	K	10	1.250	.698	10.3	4.9	2.06	.98	1.59	.754
	L		1.375	.767	13.7	4.8	2.74	.96	1.69	.59
	B		0		(S_m)	3.00				
	M	11	1.500	.837	11.9	3.2	3.97	1.07	1.79	.481
	A		0		(S_m)	1.8				
	N	12	1.625	.907	12.5	2.2	6.95	1.22	1.85	.324

spective stress concentration factors. Curves I and II in Fig. 13 present the stress concentration factors in bending for the various ratios of diameter of hole to depth of beam as determined from the data for the stresses at the edge of the hole and the edge of the beam.

For a comparison with previous work, we might first consider the approximate solution of the problem by Tuzi,[6] who suggested for Airy's stress function,

$$\phi = Aa^3\left[\left(\frac{a}{2r} - \frac{a^3}{4r^3}\right)\sin\theta + \left(\frac{r^3}{6a^3} - \frac{a}{2r} + \frac{a^3}{3r^3}\right)\sin^3\theta\right], \quad (c)$$

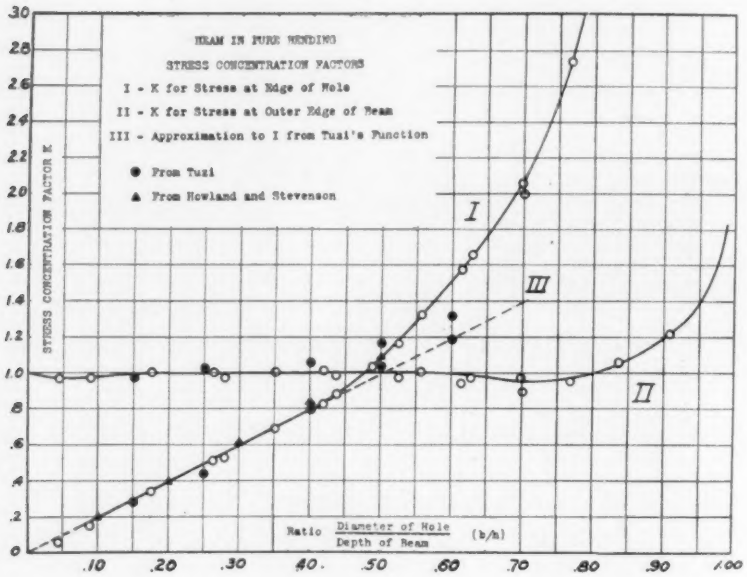
where $A = 12M/h^3$; $a = b/2$; r is the radial coördinate from the center of the hole, and θ is the angular coördinate from

the longitudinal axis of the beam, counter-clock-wise from the right.

The maximum value of the stress at the edge of the hole is given by the equation

$$S_c = \left[\frac{1}{r^2} \frac{\partial^2 \phi}{\partial \theta^2} + \frac{1}{r} \frac{\partial \phi}{\partial r} \right], \qquad (d)$$

FIG. 13.



where $r = a$, and $\theta = \pi/2$, giving

$$S_c = 2Aa. \qquad (e)$$

The maximum value for the stress in a similar beam without a hole given by Equation (d), is found to be

$$S_m = \tfrac{1}{2}Ah, \qquad (f)$$

where $r = h/2$, $a = 0$, and $\theta = \pi/2$.

Considering the ratio of Equations (e) and (f), the stress concentration factor becomes

$$K = 2b/h.$$

The values of K as given by this equation are shown on Fig. 13 as an interrupted line.

The values of K as determined from Tuzi's photoelastic data are shown on Fig. 13 as solid circles.

The exact solution developed by Howland and Stevenson [7] gives Airy's stress function in the form of an odd power trigonometric series. The coefficients of each term of this series consists of a sum of four terms, each evaluated by other series. As the ratio b/h increases, the sub-series converge less rapidly and the function has not been evaluated above $b/h = 0.5$. The values of K calculated from the solution of the above function are shown on Fig. 13 by solid triangles.

The concentration factor for the stress at the outer edge of the beam, Fig. 13, Curve II, is very close to unity for all practical values of b/h. As the diameter of the hole approaches the depth of the beam, the variation in stress is approximately a straight line across the minimum section, and suggests that the maximum stress at the hole is nearly twice the average stress in tension and compression due to bending. At the edge of the beam, the limiting stress would be zero. The distribution of tensile and compressive stress across a series of sections is shown in Fig. 14, where the abscissa are depth of sections and the ordinates are isochromatic bands of stress.

B. The Stress Concentration Factor in Compression and Tension.

It will be seen from Fig. 13 that the stress concentration factor K for the stress at the edge of the hole, Curve I, rapidly approaches infinity for the higher values of b/h. To avoid this difficulty and to make the curve more useful, another concentration factor K' is used. If a uniform tension or compression is assumed to exist across the minimum section between the hole and the edge of the beam in reaction to the bending moment applied, the maximum value of the stress concentration at the edge of the hole will be found by multiplying the value of the assumed uniform stress by the factor K'.

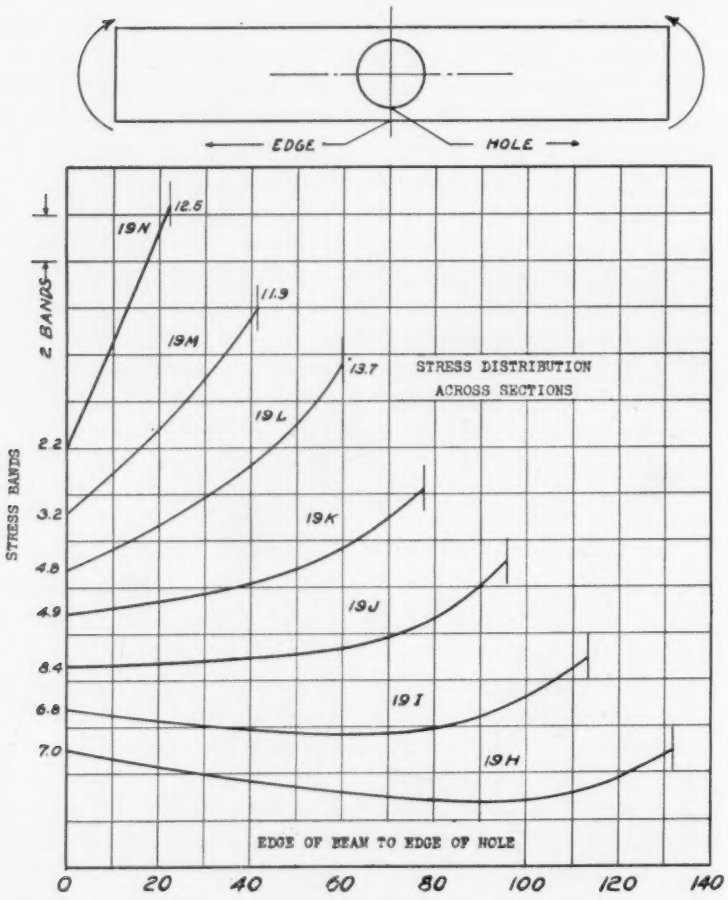
Under this assumption of a uniform stress the equivalent moment arm becomes $(b + h)/2$, and the uniform stress has the value,

$$S_u = \frac{4M}{h^2 - b^2}. \qquad (g)$$

From (*g*) and the value of S_m previously given in (*a*), the relation between K and K' is obtained;

$$K' = \frac{3}{2}[1 - (b/h)^2]K. \qquad (h)$$

FIG. 14.

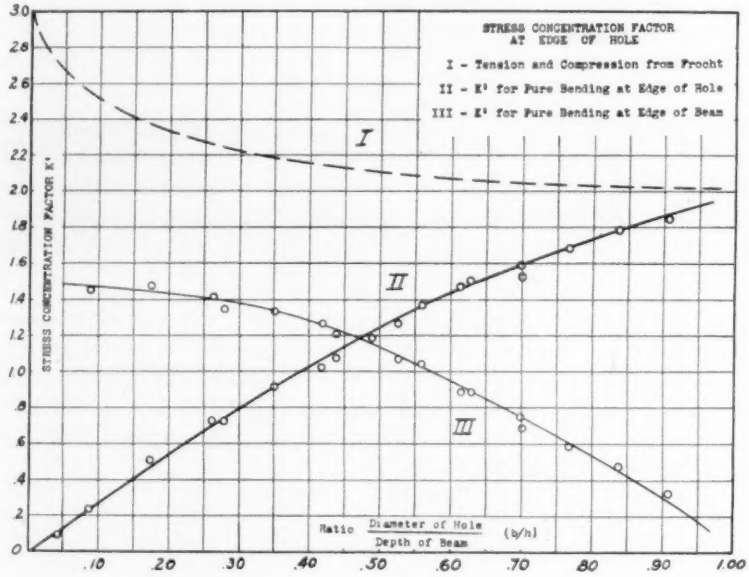


With this relationship, and the data given in Table I, the concentration factor K' for various values of b/h have been plotted in Fig. 15, Curve II. In a similar manner, the concentration factor K for the stress at the outer edge of the

beam, Curve II in Fig. 13, is shown as K' in Fig. 15, Curve III, although this curve has no practical purpose except to establish conditions of stress at the extreme limits.

K' has been suggested by and is identical to the concentration factor for the case of bars with centrally located holes under tension and compression as defined by Wahl and Beeuwkes.[2] As the minimum cross-section between the hole and the beam approaches zero, in pure bending K' approaches

FIG. 15.



the value of Wahl and Beeuwkes' concentration factor of two at the same limit. The relation between Wahl and Beeuwkes' factor and b/h as determined by Frocht [3] is therefore shown on Fig. 15 as an interrupted line.

CONCLUSIONS.

The results of these determinations agree reasonably well with both Tuzi's experimental work and the exact solution of Howland and Stevenson for the lower values of the ratio b/h, while the limiting values of K' as b/h approaches unity agree

with the limiting values of the stress concentration factors in tension and compression as determined by Wahl and Beeuwkes, and Frocht.

From these considerations, the following rules for the design of rectangular beams with centrally located holes under pure bending have been established:

1. If the ratio of the diameter of the hole to the depth of the beam is less than one-half, the maximum stress occurs on the outer edge of the beam, and its value is approximately the same value as the maximum stress that would exist without the hole. Thus it may safely be assumed that a hole of diameter less than half the depth of the beam does not reduce the strength of the beam.

2. When the diameter of the hole is greater than half the depth of the beam, the maximum stress occurs at the edge of the hole adjacent to the minimum section. It is most easily evaluated by assuming a uniform stress to exist across the minimum section, Equation (*g*), and increasing the value of this uniform stress by the stress concentration factor K' given in Fig. 15, Curve II.

ACKNOWLEDGMENT.

The authors make grateful acknowledgment for material aid in the consummation of this problem to the Graduate School and the Mechanical Engineering Department of the University of Minnesota.

GROWTH AND DECAY OF PHOSPHORESCENCE IN CALCIUM SULPHIDE BY A PHOTOELECTRIC METHOD.

BY

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Randal Morgan Laboratory of Physics.

ABSTRACT.

The phosphorescence of the calcium sulphide was excited by light and the intensity of the combined radiation of all stimulated wave-lengths was measured as a function of time by means of photoelectric cell, the current from which was amplified by a special vacuum tube amplifier. The amplified currents deflected a galvanometer, the deflection of which was found to be strictly proportional to the intensity of the light falling on the cell.

Decay curves for different durations of excitation of the sample were obtained, the decay in intensity during the first thirty seconds after excitation being automatically recorded. Similar curves were obtained for identical durations of excitation at various temperatures of the sample. The effects of several different binders for the calcium sulphide powder were also investigated. A single empirical equation for sulphide in a given binder was obtained, by means of which the intensity of the phosphorescence can be computed for any time after excitation begins, and for any temperature within the range studied.

INTRODUCTION.

Why, if light falls on certain materials, do they emit a light of their own, in addition to reflecting some of the incident light? Further, of the materials which possess this light-emitting property, why do some begin and end their emission simultaneously with the starting and stopping of the incident light, while others begin gradually and continue to glow for several minutes after the exciting light is cut off, their brightness gradually diminishing to zero?

Although much information has been gathered concerning such materials and about the light emitted by them, the above questions still remain unanswered. Perhaps more exact information is needed before a complete explanation of these phenomena can be given. Light emitted in this way is known as luminescence; the immediately extinguished effect is called fluorescence, and the continuing effect phosphorescence. It

is probable, and even likely, that the two effects are essentially the same, differing only in the value of some time factor or factors involved.

Many experimenters, notably Becquerel,[1] Lenard and Klatt,[2] and more recently Nichols, Howe, and Wilber,[3] have used different kinds of photometers or special "phosphoroscopes" for investigating the decay of phosphorescence with time.

The development of the photoelectric cell has naturally led to its use as a means for further study of phosphorescent materials. Lenard and Hauser [4] used a photoelectric cell and an electrometer with a suitable capacity. However the photoelectric cell is scarcely sensitive enough to be used with a galvanometer without an amplifier when the light to be measured is faint, and especially when it is desired to record the galvanometer deflections. The work here reported consists in measuring the growth and especially the decay of phosphorescence of calcium sulphide, excited by light, by the use of a photoelectric cell and amplifier combination well suited to such measurements.

DESCRIPTION OF APPARATUS.

The device employed in this investigation to measure the light emitted by the phosphorescent sample was the photoelectric cell and high grid resistor amplifier as used in the Razek-Mulder Color Analyzer.[5, 6, 7] A photograph of this Color Analyzer is shown in Fig. 1. This instrument is an automatic recording photoelectric spectrophotometer. A number of small light bulbs are mounted in a hemispherical holder, and the sample to be tested is placed over an opening at the center of the plane surface of the hemisphere (upper left in Fig. 1, showing magnesium carbonate ready to be tested). Thus the sample is illuminated from many direc-

[1] Becquerel, "La Lumiere," I, 285 (1867).
[2] Lenard and Klatt, *Ann. der Phys.*, **38**, 90 (1889).
[3] Nichols, Howe, and Wilber, *Phys. Rev.*, **12**, 351 (1918).
[4] Lenard and Hauser, "Heid. Zit. Ber." (1912).
[5] Mulder and Razek, *J. O. S. A.* and *R. S. I.*, **18**, 466 (1929).
[6] Razek and Mulder, *J. O. S. A.* and *R. S. I.*, **19**, 390 (1929).
[7] Razek and Mulder, *Phys. Rev.*, **33**, 284 (1929).

tions. The light that is reflected normally from the sample passes down through an adjustable slit into a spectrometer, where the light is dispersed into a spectrum. A predetermined portion of the spectrum is allowed to emerge from the spectrometer through a second adjustable slit. Both entrance and exit slits are adjustable so as to keep the emerging wave-

FIG. 1.

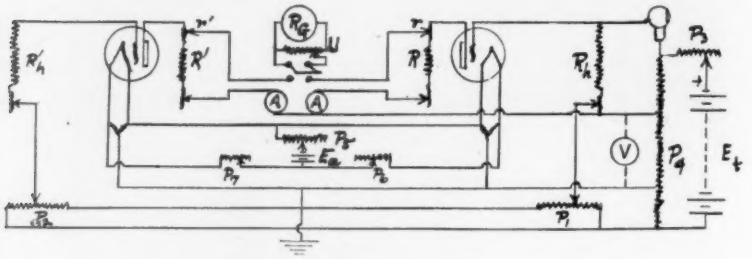
length band of the same width, about ten millimicrons, throughout the spectrum. The emerging light falls upon two photoelectric cells, one blue sensitive potassium hydride, and one red sensitive cæsium oxide. Both cells are connected in parallel, with the optimum voltage in series with each, across the high resistance of a high grid resistor amplifier.

This amplifier consists in brief of an amplifying vacuum tube of high mutual conductance, having its grid circuit resistance (100 to 2000 megohms) adjusted according to the

degree of vacuum of the tube under the voltages employed, to render the combination highly sensitive, that is, of very high effective mutual conductance; and of a second similar tube similarly operated, connected into a bridge circuit in parallel with the amplifying tube, to compensate for battery voltage fluctuations. The circuit diagram, with only one of the photoelectric cells, is shown in Fig. 2. An output galvanometer is connected across two points in the bridge circuit which remain at the same potential so long as the cells are dark. For a more detailed description of this circuit see the references cited.

The operation of the photometer unit of this Color Analyzer is as follows. When light is allowed to fall on the

FIG. 2.



The bridge grid resistor amplifier circuit.

photoelectric cells the photoelectric current flows through the high resistance, causing an RI drop in the resistor, and thereby altering the potential of the grid of the tube. Since the tube has been adjusted to have an extremely high effective mutual conductance this change in grid potential results in a very large change in plate current. The plate current increase alters the potential of one terminal of the galvanometer, and thereby causes current to flow through the galvanometer. This galvanometer current is taken as a measure of the intensity of the original light.

The galvanometer can be read from a scale just above the amplifier near the right of the figure (Fig. 1). Its reading can also be recorded by inserting a film through the small door at the upper right. A wave-length scale can be seen at the right

of the galvanometer scale. The instrument is made automatic, so that by turning the small crank shown at the lower right in the figure, the spectrum is scanned from violet to deep red; both entrance and exit slits are adjusted to give the correct wave-length band; a film is advanced which records the position of the galvanometer, or the intensity of the light; and adjustment is made in the energy admitted to the spectrometer so that the galvanometer deflection for a standard white surface is approximately constant throughout the spectrum.

If then consecutively, a record is made for a standard white surface (magnesium carbonate) and for a colored surface to be tested (about ten seconds is required for each record) the ratio of the two galvanometer deflections, unknown to standard, read from the record, at a given wave-length gives the reflection factor at that wave-length. This ratio may be taken successively at all wave-lengths, yielding the reflection factors at all wave-lengths. When the reflection is known for all wave-lengths the color of the sample is determined.

DISCUSSION AND PROOF OF LINEARITY.

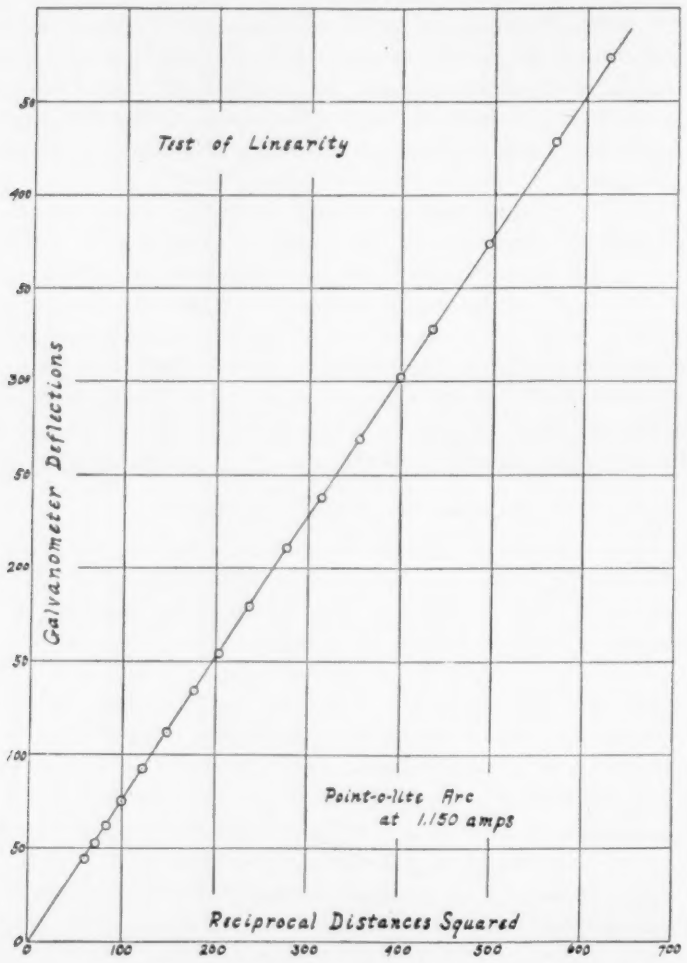
It is, of course, of highest importance that the relation of galvanometer current to the intensity of light incident on the photoelectric cell be known, and it is desirable and most convenient if this relation be linear. Many experimenters with photoelectric cells have taken for granted that it could not be made linear.[8, 9, 10, 11] The cell has been used by them merely as a judge of equality of intensity rather than as a measure of the intensity itself. Of course, it is well known that for fairly high intensities, such as considerable fractions of one lumen, photoelectric cells do not yield currents proportional to intensity, but for low intensities such as result in any apparatus including a spectrometer many cells do yield currents proportional to intensity.

These photoelectric currents which are proportional to the light intensity cause grid potential changes that are also proportional to the light intensity. If the amplifying tube be

[8] Hardy, *J. O. S. A.* and *R. S. I.*, **18**, 165 (1929).
[9] Barnard and McMichael, *J. O. S. A.*, **21**, 588 (1931).
[10] Ives and Kingsbury, *J. O. S. A.*, **21**, 541 (1931).
[11] Sharp and Eckweiler, *J. O. S. A.*, **23**, 246 (1933).

operated on a portion of its grid-voltage-plate-current characteristic that is linear the corresponding changes in plate

FIG. 3.

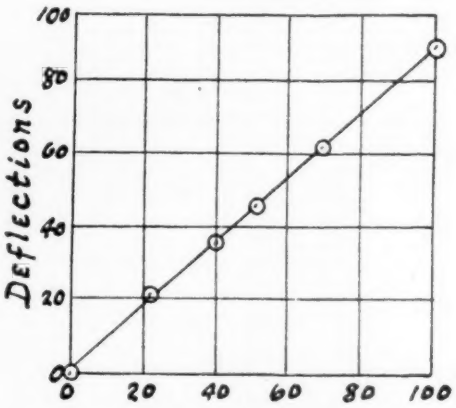


Test of linearity.

current will be linearly related to the light intensity, and consequently the galvanometer deflections will be also. It is thus possible that the galvanometer deflections may be proportional to the light intensities.

This relation has been verified by experiment. Using a Point-o-lite lamp, at constant current and voltage, at different distances the galvanometer deflections were found proportional to the inverse distances squared as shown in Fig. 3. In this test the departure of any reading from true linearity was not greater than one-tenth of one per cent., and the range tested was more than four times that normally employed in the Color Analyzer. Here then is experimental proof that in the complete Razek-Mulder photometering device the galvanometer deflections are proportional to intensities.

FIG. 4.



Inverse distances squared.

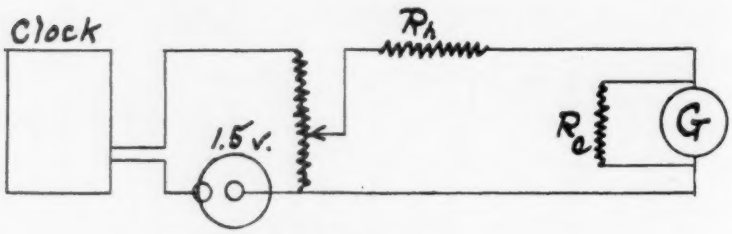
In the work on phosphorescence the single change made in the standard Razek-Mulder photometering device was the omission of the cæsium oxide red-sensitive cell in as much as the samples to be tested emitted only violet light. Since linearity is so important and since the source of excitation was adjustable in distance from both the sample and the photocell, check readings on this particular cell and amplifier combination were taken. A diffusing screen consisting of a piece of almost opaque paper was inserted in place of the sample. This screen was then illuminated by the exciting lamp at various distances. The resulting deflections were plotted against the reciprocals of the distances between the exciting

lamp and the opaque paper, squared, as shown in Fig. 4. Of course this check could not be as accurate as that previously mentioned, yet undoubtedly it also proved linearity for the particular combination of cell and amplifier.

APPARATUS FOR AUTOMATIC RECORDING.

When it was desired to record the intensity of the phosphorescence as a function of time, it was found that the Razek-Mulder Color Analyzer could easily be adapted for this purpose. It was equipped as was explained before, to record intensity at the various wave-lengths of the spectrum. It was only necessary, therefore, to replace the wave-length mechanism with a time mechanism.

FIG. 5.



Time signal circuit.

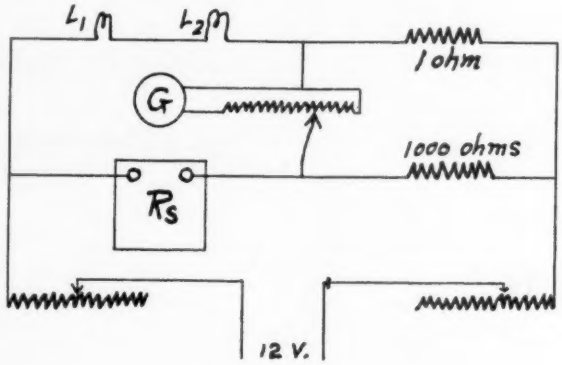
This was accomplished by disconnecting the wave-length mechanism and attaching a small motor to drive the recording film approximately at constant speed. A low voltage was connected to the higher sensitivity galvanometer to the Color Analyzer with contact through a gear of an electric clock, as shown in Fig. 5, the gear moving at the rate of one tooth per second, thereby causing this galvanometer to deflect once every second. The voltage was adjustable to permit control of the amount of deflection. Consequently there was imprinted on the films the records of two galvanometers, one for the light intensity, and one for the time. It was found that the first thirty seconds of the decay, where the change in intensity is rapid, could thus be recorded on films photographically. For the later part of the decay curve, where the intensity decreases slowly, visual readings of the deflections were taken.

EXCITING SOURCE AND CALIBRATION LAMP.

The source for exciting the sample was a 15 c.p. 6 to 8 volt bulb maintained at constant resistance in a Richardson bridge. It was adjustable in distance from the sample. A heat absorbing filter was placed between the exciting source and the phosphorescent sample.

The calibration lamp consisted of a second similar bulb also maintained at constant resistance in the same Richardson bridge, the two bulbs in series forming one arm of the bridge. The second arm was a decade box, and the other two were oil-immersed standard coils. At the beginning the resistance of

FIG. 6.



Richardson bridge.

the decade box was adjusted for a balance, and thereafter only the voltage applied to the bridge was varied to obtain or maintain a balance. Once balanced, this bridge remained constant within plus or minus three-tenths per cent. of the standard lamp deflection for long periods of time. Its circuit is shown in Fig. 6.

PREPARATION OF THE SAMPLES.

The samples tested were Calcium Sulphide of unknown origin and history. Many results were obtained from the powdered sulphide packed closely against a glass plate. Later however, samples were prepared by mixing the powdered calcium sulphide with Duco thinner, spreading as uniformly as possible on a glass plate, and allowing to dry. Clear

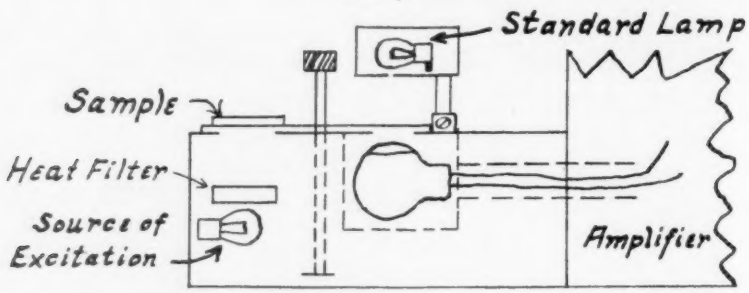
varnish was also used as a satisfactory vehicle. The powder samples were excited by exposure to light and their luminosity measured on the same face. The Duco thinner suspended samples, and the varnish bound samples were excited on one side and tested on the opposite side.

For the purpose of investigating the effect of temperature, two thermometers were affixed to the varnish bound samples, one on each side of the sample. They were attached in contact with the glass on the same side on which the sample was mounted. A heater was placed in the compartment with the sample for altering its temperature.

ARRANGEMENT OF SAMPLES.

For the powder samples packed against glass the arrangement was as shown in Fig. 7. The sample was mounted face

FIG. 7.



Arrangement for sample in powder form.

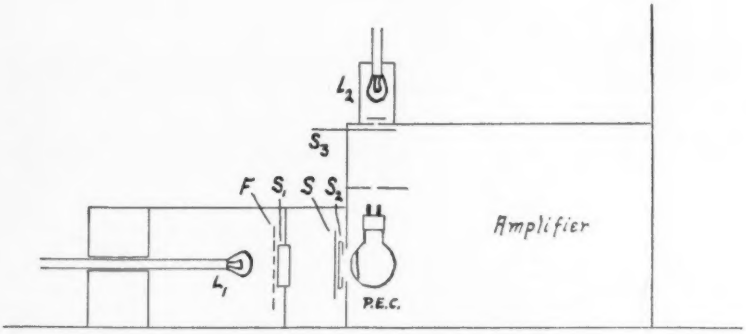
down on a disk with a vertical axis so that it could be rotated from the exciting lamp to the measuring photoelectric cell. A hole in the disk allowed light from the standard lamp to fall on the cell. It was found impossible with this arrangement to get readings earlier than five seconds after the excitation was cut off.

Figure 8 shows the arrangement used later for the Duco thinner or varnish bound samples. The sample S, exciting source L_1, and standard lamp L_2, were all stationary, the shutters S_1, S_2, S_3, being used for the deflections.

The steps in taking a test were as follows. When everything was in adjustment and functioning properly, the sample

having been dark for at least an hour, the two thermometers were read. The shutter S_1 was opened sharply by a clock to allow the sample to be excited. While the sample was being excited a calibration deflection was taken by opening and then closing shutter S_3. About three seconds before the excitation was to be ended the switch was closed to start the motor driving the film. At the end of the chosen excitation period, shutter S_1 was closed, stopping the excitation, and S_2 opened simultaneously, allowing the photoelectric cell to measure the intensity. Then after a few seconds shutter S_2 was closed and S_3 opened to record the standard lamp. During the

FIG. 8.



Arrangement for varnish bound samples.

thirty seconds of recording these two shutters were opened alternately at intervals, sometimes automatically and sometimes by hand. Meanwhile the time signal was constantly being recorded. A switch was inserted in the film holder so that it broke its own motor circuit at the end of its run. Thereafter for several minutes visual observations of the deflections were taken. Both thermometers were read at the end. Finally the visual calibration deflection was repeated.

RESULTS.

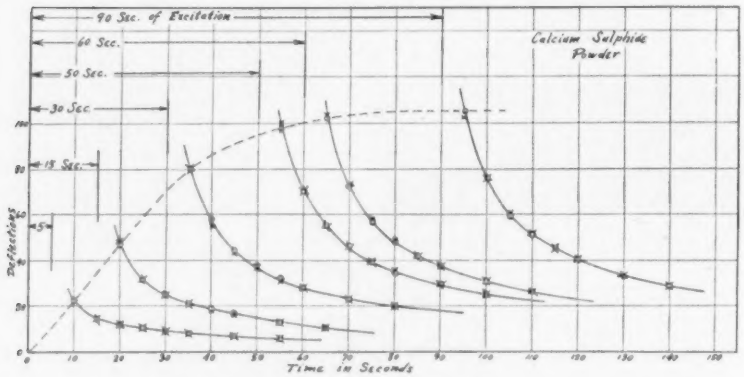
Many phosphorescent samples show a change of color with decay, due to a shift in the wave-length of maximum emission. No such change of color for the calcium sulphide samples here studied could be seen by eye. Furthermore, the range of

wave-lengths in which the photocell was sensitive was considered sufficiently broad to include the small amount of change which, though imperceptible to the eye, might exist. It is to be remembered that the total light received by the cell was measured, and that no attempt was made to separate the light spectrally. Consequently the results as here presented are for the total or integrated intensity.

RESULTS BY VISUAL OBSERVATION OF GALVANOMETER.

Figure 9 shows graphically the results obtained on the

FIG. 9.



A series of results from calcium sulphide powder.

powdered samples. The different curves are for successively increasing times of excitation. The time of excitation for any curve is from the zero of the time axis to the heavy vertical line. The dotted line joins the deflections taken five seconds after the excitation was stopped. It is obvious from these curves that the intensity immediately at the end of excitation is large, and that it is desirable to obtain earlier observations. To obtain the earlier values the method of recording the deflections automatically was employed.

RESULTS BY AUTOMATIC RECORDING.

Figures 10 to 13 are copies of sample records taken by this later method. The ink lines were drawn in by hand to facilitate reading the records. The dotted curves between the

FIG. 10.

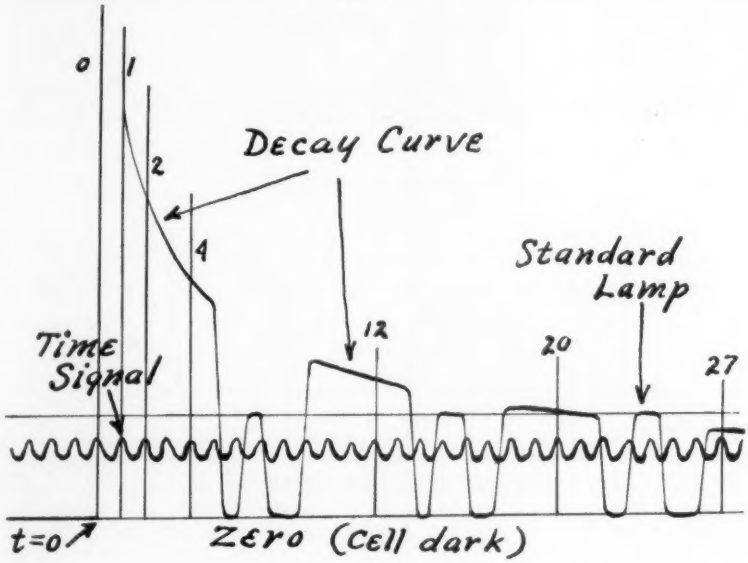
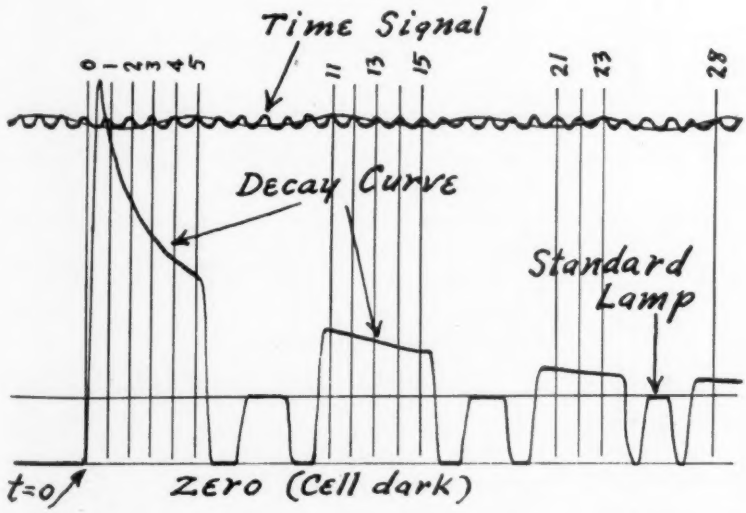


FIG. 11.



photographed parts were also drawn in, to emphasize the shape of the curve. It can be seen from these records how the shutters were operated to register zero, standard, and unknown

FIG. 12.

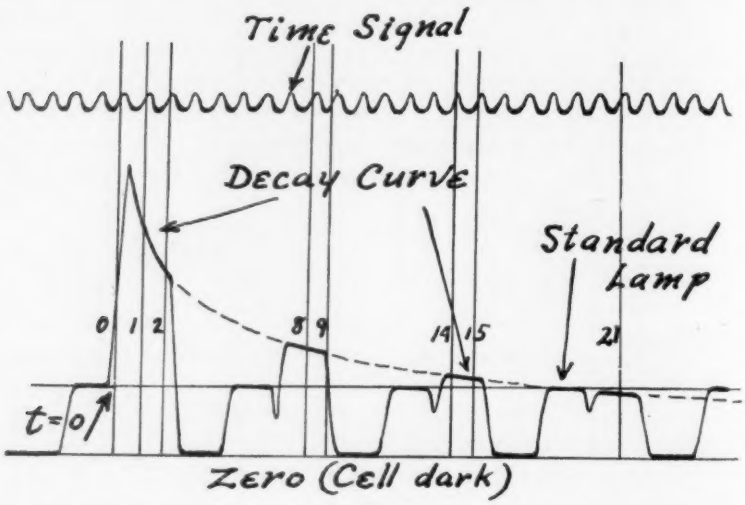
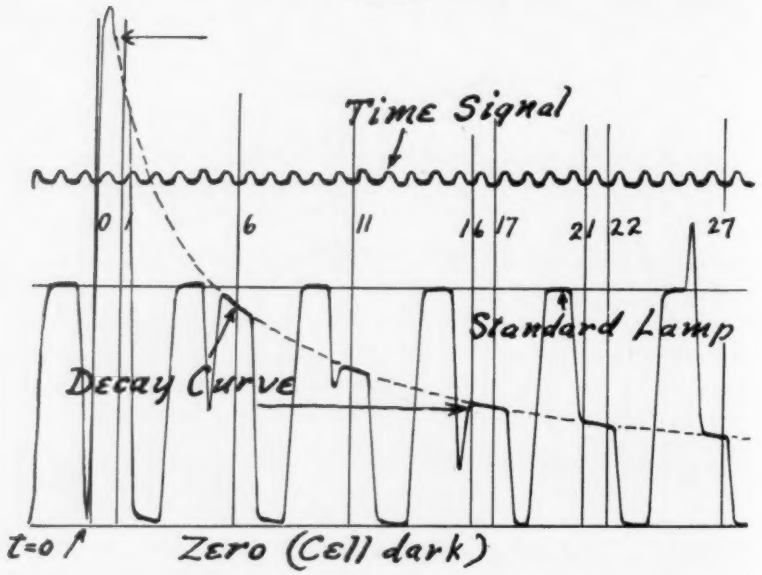


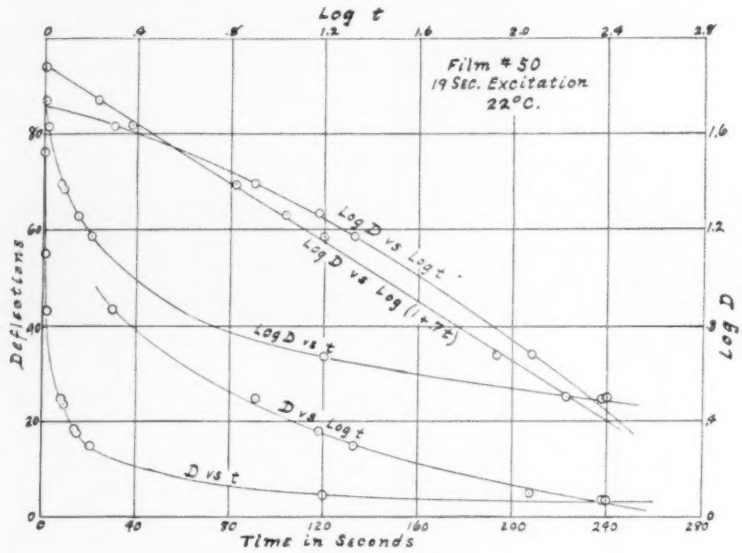
FIG. 13.



successively. For films No. 50 and No. 55 the shutters were operated automatically. For films No. 37 and No. 47 they were operated by hand.

Figure 14 shows the record from film No. 50 plotted in various ways, one of which gives a straight line. This figure is shown as typical of very many sets of readings for which by similar treatment the straight line relation was obtained. Among them is the set of readings represented graphically in Fig. 9, for times of excitation varying from 5 to 90 seconds.

FIG. 14.



Typical graph of results.

FORMULÆ.

The equation of the straight lines in Figs. 14 and 16 is of the form

$$\log D = \log A - k \log (a + bt), \qquad (1)$$

where t is the time of decay. Writing this in the ordinary manner

$$D = \frac{A}{(a + bt)^k}, \qquad (2)$$

which is of the form obtained by others and well known.

From the results shown in Fig. 9 it was found that the numerator, A, varied with the time of excitation and could be

closely expressed by

$$A = Bt_x - Ct_x^2 + Dt_x^3 - \cdots, \tag{3}$$

where t_x is the time of excitation. It was also found that "a" depended on the time of excitation, and was of the form

$$a = \epsilon + at_x. \tag{4}$$

Substituting (3) and (4) into Eq. (2) gives

$$D = \frac{Bt_x - Ct_x^2 + Dt_x^3 - \cdots}{(\epsilon + at_x + bt)^k}. \tag{5}$$

FIG. 15.

k		.590	.690	.690	.710	.720	.725
tx		5	15	30	50	60	90
D_0	Observed						
	Computed	95.5	173	208	211	204	173
D_5	Observed	23	47	80	97	102	105
	Computed	21.8	48.7	80.6	100.1	104	102.5
D_{10}	Observed	15.6	32	58	70	72	76
	Computed	14.9	32.1	55.0	70.2	73.5	75.8
D_{15}	Observed	12.4	25	44	55	56	59
	Computed	11.9	24.8	42.9	55.6	58.7	61
D_{20}	Observed	10.6	21	37	46	48	51
	Computed	10.0	20.5	35.9	46.5	49.3	52
D_{25}	Observed	9.0	19	32	39.5	42	45
	Computed	8.8	17.7	31.0	40.5	42.7	45.6
D_{30}	Observed	8.0	17	28	34	38	41
	Computed	8.0	15.7	27.8	36	37.8	40.5
D_{40}	Observed	7.2	12.6	23	30	31	33
	Computed	6.7	12.9	23.2	29.6	31.3	33.7
D_{50}	Observed	6.0	10	20	25	26	28
	Computed	5.9	11.1	19.8	25.5	27	29.2

Table of typical results.

By using $B = 12.3$, $C = .08$, $a = .05$, $D = .0001$, $\epsilon = .2$, and $b = 1$, values were computed from this equation for the deflections shown in Fig. 9, and are indicated in the figure by crosses (x). The table of values is given in Fig. 15, the upper number being the observed deflection, and the lower that computed from the formula.

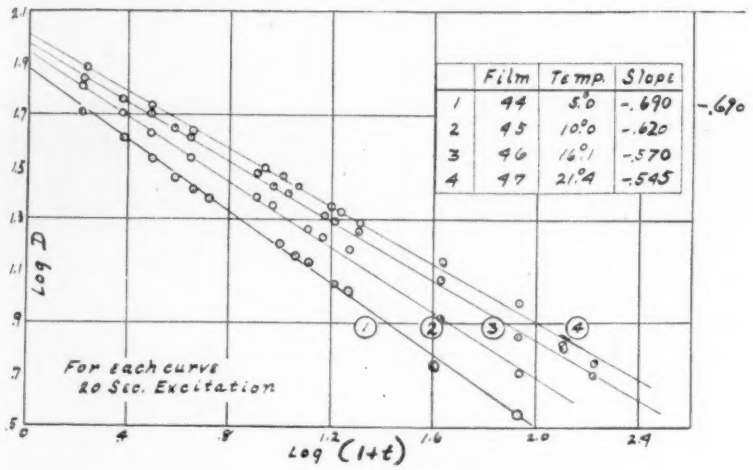
For zero time of decay ($t - 0$), this Eq. (5) becomes

$$D = \frac{Bt_x - Ct_x^2 + Dt_x^3 - \cdots}{(\epsilon + at_x)^k}, \qquad (6)$$

which is an equation for the intensity of phosphorescence during excitation, or for the growth of the phosphorescence.

It seems that "b" in Eq. (5) may depend on the binder used for the calcium sulphide powder. At least, for the powder sample with no binder, excited and tested on the same

FIG. 16.



Effect of temperature.

face, $b = 1$. For a sample made with Duco thinner which, when dry, left a thin layer of powder on the glass plate with practically no binder, tested on the side opposite the exciting source, $b = 1$. However, for all samples made with clear varnish as binder, $b = 0.7$.

EFFECT OF TEMPERATURE.

Figure 16 is a set of curves for a series of temperatures of the phosphorescing calcium sulphide, the particular temperatures being indicated in the figure. Here it can be seen that the slope of the curve changes with the temperature, and also that the initial intensity, or brightness just at the beginning of

the decay, increases with the temperature. However, the change of temperature does not alter the shape of the curves, as was reported by Ives and Luckiesh.[12]

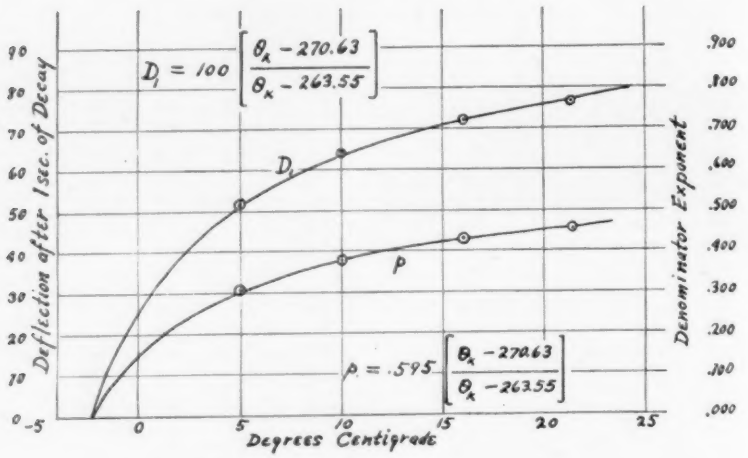
The slopes of these curves, being negative and less than unity, may be expressed as

$$k = -1 + p,$$

where "p" is also less than unity, but positive.

In Fig. 17 both D_1, the deflection one second after excitation was cut off, and "p," the positive part of the denominator

FIG. 17.



Deflections and exponents vs. temperature.

exponent, are plotted against the temperature of the sample. Here it can be seen that both D_1 and "p" are non-linear functions of the temperature, both tending to approach limiting values. Closer inspection suggests that they may be similar functions of the temperature. Upon trial it was found that D_1 at any temperature equals $168p$ at the same temperature.

An empirical equation was found by which "p," and therefore, D_1, can be computed in terms of the temperature of the sample and of two critical temperatures of the material of

[12] Ives and Luckiesh, *Astrophys. Journal*, **36**, 330 (1912).

the sample. This equation is

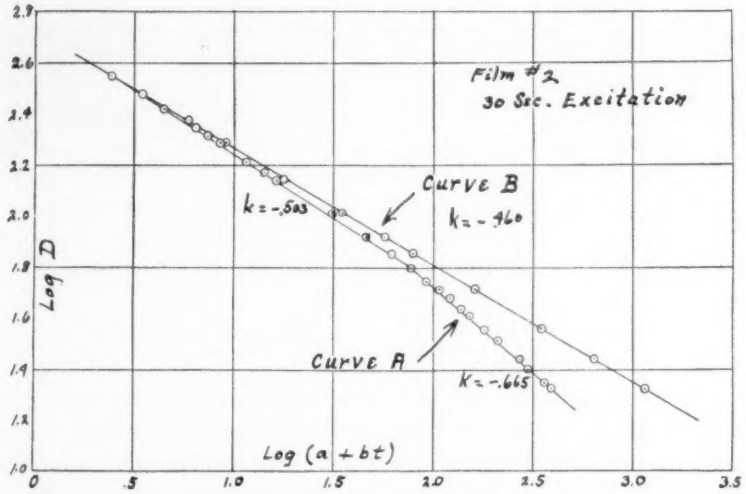
$$p = \frac{\theta - 270.63}{\theta - 263.55}(.595),$$

where θ is in degrees Kelvin. The solid line curves in Fig. 17 were drawn by plotting the values computed by means of this equation. It is to be noted that the experimentally determined values, shown encircled, fall very closely upon the curves.

LONG RANGE DECAY.

The severest test of any empirical equation is the case for which the observations cover the widest range. A typical set

FIG. 18.



of results for which the observations were continued until the brightness had diminished to one fiftieth or one-one hundredth of its initial value is shown in Fig. 18. When the logarithms of the deflections were plotted against the logarithms of $(a + bt)$, as for Figs. 14 and 16, curve A was obtained. It is to be noticed that after the first 90 or 100 seconds the curve departs from a straight line, and also that the points thereafter fall roughly along another straight line of greater slope, indicating possibly two different rates of decay, as was

suggested by Lenard,[13] and by Nichols, Howe, and Wilber.[14]

However, if a term in t^2 with a very small coefficient (.005 in this case), is added in the denominator of the equation, all points then fall on the single straight line, curve B in the figure, and, as can be seen in the figure, more accurately on the line than without the extra term. For the broken curve, A, it is necessary that the denominator exponent, k, be a discontinuous function of the time of decay, whereas the addition of the higher power term in t makes k have a single value throughout the entire process.

Consequently the final formula given as an adequate representation of all data is

$$I = \frac{K(Bt_x - Ct_x^2 + Dt_x^3 - \cdots)}{(\epsilon + at_x + bt + ct^2)^k}, \qquad (7)$$

where K is the constant of proportionality between the intensity, I, and the galvanometer deflection, D. It is suggested that both the numerator and the denominator in this equation may be the first few terms of two rapidly converging series. It is to be noted that this equation gives zero intensity before excitation begins, gives a maximum in intensity during excitation, predicts a whole family of decay curves closely, and finally gives zero intensity again after sufficiently large values of time.

CONCLUSION.

The results here reported were obtained by the use of a photoelectric cell with an amplifier, so that the intensity of the phosphorescence could be automatically recorded on photographic film. The form of the equation for the decay of phosphorescence had been obtained by others, $I = A(a + bt)^{-k}$, where t is the time of decay. An interpretation of the constants in this equation is made here, resulting in Eq. (7). It is possible from this work to indicate definitely which of the coefficients or terms in the formula are functions of temperature, which are functions of the time of excitation, and to some extent what the form of the function is.

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[13] Lenard, *Ann. der Phys.*, **31**, 641 (1910).

[14] Nichols, Howe, and Wilber, *Phys. Rev.*, **12**, 351 (1918).

It is realized that the equation presented is entirely empirical, but the accuracy with which it predicts the intensities is significant. It must be noted that the equation predicts the entire process of phosphorescence from dark to dark. There are at least three theories for the time-intensity relations in phosphorescence, but none of the three seems entirely adequate, and there is need for a more thorough development of one of these, or for an entirely new theory. Equation (7) should be of assistance in the revision of the older theories or in the formulation of a different one, since it expresses compactly a large amount of data and indicates the trend of the physical factors involved.

I wish to thank my friend, Dr. Joseph Razek, for his collaboration in the test for linearity, the results of which are given in Fig. 2. I also wish to express my thanks to Professor C. B. Bazzoni, under whose direction this work was carried on, for his many valuable suggestions and interest.

Test New Corn Seedlings With Artificial Drought.—Corn farmers in the Great Plains area frequently are confronted in midsummer with days, or even weeks, of high temperatures with low humidity and deficient soil moisture. Under such conditions it is necessary in any corn improvement program to know the tolerance of any new strain to drought and high temperatures. Wide variations in weather from year to year make testing of this tolerance under field conditions uncertain. Unfavorable weather ideal for testing any new strain may not occur in any year or even in a succession of years. Specialists of Kansas State College devised a simple heat chamber with thermostatically controlled heat for testing the resistance of plants to heat. A small fan keeps the air in motion and insures uniform temperatures. Corn specialists of the Kansas station and the United States Department of Agriculture placed 14-day-old seedlings in clay pots in the chamber at a temperature of 140° F. and a relative humidity of about 30 per cent. These seedlings showed a great difference in resistance to drought conditions. Some strains withstood the heat for several hours and when returned to normal growing conditions recovered 100 per cent. Others failed to recover. These same corn strains reacted almost identically in field plots in a drought year, showing the accuracy of the tests in the artificial drought chamber.

R. H. O.

"UP IN A BALLOON, BOYS."

BY

W. N. JENNINGS,

Member of the Institute.

The home of my lifelong friend, "Professor" Samuel A. King, was reminiscent of many a balloon ascension. A hole in the porch roof was patched with a piece of fabric from the old "Excelsior" aerostat. The overturned basket of the ancient "Uncle Sam" made an excellent chicken coop. Mrs. King was hanging up clothes on a line that once was a drag-rope; while her grand-daughter used a part of the same material for a swing, and her brother trundled a hoop salvaged from the "Eagle Eyrie" balloon.

I found the "King of the air" in high good humor, as usual; his six foot three stretched out in a hammock made from the net of an old sky-sailer, his eye as blue and his whiskers as white as the sky and clouds he had so often sailed in.

At King's invitation I took a seat in a porch chair (cushioned with ballast bags), and soon we were soaring skyward, in retrospect, recalling, with many a "Do-you-remember-when?", incidents of our many joint skylarks.

"That time you almost lost your new camera?" chuckled the Professor.

Upon the initial flight of the eight passenger "Ben Franklin" balloon, I had undertaken to photograph, with my new aero-camera a christening group, at the height of a mile, and finding I could not include all the members of the party within the angle of the lens, I suggested to my friend, Arthur Atherholt, that while I sat on the edge of the oval basket and leaned far back, he should sit on my feet. This human cantilever worked to perfection, but when I pulled myself back to normal, I noticed that Atherholt's face was white as chalk, and his marble brow was beaded with sweat.

"What's the matter, Arthur?" I asked.

"Oh, migod," he gasped, "when I saw you out there a mile up in the air, with nothing to hold on to but your camera, I got 'cold feet' and almost fainted."

"And then, you boob, I should have lost my new graflex," I retorted.

"But, Professor," I remarked at last, "this gabfest almost made me forget the object of my visit. You promised to

First balloon photograph of Fairmount Park. Note the surface ripples in the rear of the gasoline launch "Yankee Doodle" and the sub-aqueous ripples ahead. These latter are invisible from the shore line, but clearly visible from a balloon. Photograph taken July 4, 1893.

write me a story of one of your adventures in cloudland to give people who are beginning to ride in these noisy, bumpy airplanes, an idea of what they are missing by deserting the balloon. How about it?"

"Here it is, in my own handwriting, headed: 'Up in a Balloon, Boys,'" said the Professor, and this is King's own story:

'Ben Franklin" eight passenger balloon. Constructed by Samuel A. King for the Ben Franklin Balloon Association of Philadelphia, the first aeronautical Society in America.

UP IN A BALLOON, BOYS.

BY

SAMUEL A. KING.

Allied with the wind, and easily borne to the loftiest cloud elevations, the spherical balloon becomes an aeronautical observatory, commanding the most extensive views of the earth and the clouds. This, indeed, has been its prerogative for nearly a century and a half, and may be considered to be its main reason for being, but it has value also as a source of enjoyment in producing other thrilling sensations and adventures for the aerial voyager.

The wind is rather arbitrary about choosing the route, but the aeronaut consoles himself for his loss of authority with the idea that he could not do as well if he had his own way. It may seem an odd statement to make, but it is a fact, that I cannot recall a single instance in all my experience when the wind proved a false friend. If it bore me out upon the ocean wide, it failed not to bring me back to land; if it carried me far off into the wildernesses, it found me a safe harbor every time; if it took me against my will to the very heart of the most violent thunderstorm, immediately thereafter it set my feet again in safety upon the solid ground. What more could one ask?

But it follows that aerial voyages must vary greatly in their particulars, and in their surprises. I call to mind one Fourth of September morning when my balloon was the center of attraction for the citizens of Cleveland, gathered in and about Monument Park, and that about eleven o'clock on that same morning six exceedingly confident individuals ascended from beside the Perry Monument in a monster balloon. The musical portion of the company had been in training for the rise, and as soon as the shouting of the multitude began to abate, the concert started with the following glee:

Up from the earth through the ether,
Swifter than eagles we soar to the sky;
High over mountain and river
And forests and rivers we fly;
Borne on the wind's fleetest pinions,
We roam in the far distant blue;

We visit the Storm King's dominions,
And gaze on his mountains of dew;
Then onward our chariot dashes;
We are joyous as sprites on the wing;
We are free as the lightning's bright flashes,
As the echoes that answering sing.
Up from the earth through the ether
Swifter than eagles we soar to the sky;
High over mountain and river;
Over forests and cities we fly.

Cleveland, for a little while, was spread beneath our feet, and as readily scanned as a model of the same upon a table. Every avenue; every house and tree; the crooked Cuyahoga river in its midst; the handsome Park from which we had ascended; the dense mass of humanity still there; all and much more seen at a glance, were sharply and clearly defined.

The balloon, hesitatingly, hung around the city for a few minutes, then in a most deliberate manner, floated out over Lake Erie, then passed over the water crib, the source of the city's water supply, which presented a singular appearance from our elevation, and we answered the call of some men on the roof of the structure. Every one was using his optics to the best advantage, but the city and shore views were drifting rapidly away. My companions would have preferred the landscape, no doubt, to the barren water waste, yet, when I questioned them, no one expressed dissatisfaction at the outlook. Captain Whiting of the *Cleveland Leader*, an elderly man, remarked that he was right at home, having followed the water all his life. This gave me a hint that if each one had some duty to perform I might have a helpful crew; so I gave the Captain charge of the compass and spy glass. Mr. Whitehead of the *Plaindealer*, was busy taking notes, and without looking up remarked that he didn't mind the water; he hadn't drank anything else all his life. That he might not be restrained from getting all he wanted, he was appointed Controller of the Water Supply. Mr. Cozad, arrayed in blue and gold, as Commodore of a yacht club, swore in nautical terms that he, too, loved the water, and was appointed Cable Master, to have care of the drag-rope and anchor. He assumed his duties at once by hanging out that valuable appendage, termed the drag-rope, thereby making ready for

any emergency. Mr. Chapman, of the *New York Herald*, claimed positive knowledge of something besides water in one of the hampers, and being anxious to serve as Commissary, received that appointment. Mr. Holden, of the *Boston Journal*, became Geographer and General Scientist, charged with keeping a time record of several instruments, which, he said, had no more preference for land than water. In adjusting our freight it was found that we had sixteen bags of sand of sixty pounds weight each; two hampers or baskets of provisions; two five gallon cans of ice water, and one *Life Preserver*. The latter article had been purchased in Cleveland by Cozad that morning, and proved to be the only one on sale in the city. So various plans were made to make this one life preserver to do duty for all, in case of necessity for its use; but the problem was beyond solution, until I informed my fellow voyagers that I had a hundred life preservers hidden away under the seats; the same being in the form of empty tomato cans, hermetically sealed and forced into a fire hose.

"How are we heading, Captain?" I inquired. "What does the compass say?"

"I can't make it out," he replied, after some hesitation. "This ship has neither bow nor stern; keeps running this way and that, and stands still all the time she's going."

"Well, never mind," I said. "Put the compass in your pocket; she will steer just as well without it."

Our course down the Lake was also diagonally towards the middle. Cleveland was soon out of sight, but its locality was known by the cloud of smoke hovering over the city. With the aid of glasses we could make out towns and villages along the shore, and even farm lands and forests, more or less foreshortened by the distance, were observed as far away as Erie, Pa.; then all detail was lost and the shore lines on both sides of the Lake were simply dark, almost black curbs, showing the north and south boundaries of the Lake. The outlook lacked nothing in vastness, for the Lake was another sky—a mirror more than two hundred miles long; but its sum of entertainment for balloon parties was small compared with overland routes. We were limited to seeing ourselves upside down in the big mirror, and to having two suns shine

on us; one from below, and the other from on high; while shadows and reflections of passing clouds, chasing each other over and under the water, was a novel sight, as long as the sun was predominant; but this was about all; and yet, it was argued, the view of that great Lake from our lofty central standpoint, of itself, alone, was the equal of any we might have found elsewhere.

It was after such a discussion that the Commissary called attention to the fact that we had not dined and wined. Our car was acorn shaped, but elongated to an oval form; the projecting portion on the outside forming the seats, while our feet rested in the center or well. This gave us all the room we required for the extension of our temporary table. The open air is always a good appetizer; but add thousands of feet above everything earthly; admit that we were sole proprietors of the atmosphere at this height, and possessed of the main comforts of life in profusion, and it follows that cloud-high picnics must claim preëminence over all others. Toasts were drunk to the memory of the first balloon makers, and to those who have brought the art to its greatest perfection.

Mr. Whitehead said he would like to try a scientific experiment (everything done up-in-a-balloon is called scientific). He produced an empty champagne bottle; filled it with water, and without corking it, dropped it over the side of the car. In two or three seconds the air rushing into the bottle drove all the water out in such a fine spray that it formed a pretty little snow-white cloud; but Whitehead was telling us to listen as a shrill whistle was telling how empty the bottle was.

The sky, which till now had been tolerably clear of clouds, began to be overcast, at first with a thin haze, but with increasing density. We had been contemplating a continuous flight to, and beyond, the easternmost end of the Lake, but the loss of the sun's rays changed the programme. There was such frequent expenditure of sand; such uncertainty as to the result of the increasing cloudiness, that we concluded to fall back upon that valuable adjunct, the drag-rope, knowing full well that it could be relied upon to save the precious sand ballast.

Down we came, checking the descent at last, by depositing a portion of the rope upon the water. Instead of continuing

on down the Lake, the wind took us back, but still with an inclination towards the Canadian shore. This part of our journey, near the water, was in strong contrast to that of the greater altitude. Instead of "standing still while going," the wind and the drag-rope, pulling in opposite directions, frequently brought the car within a few feet of the water, so that more than once it seemed almost certain we should need a boat more than a basket; but then the balloon would rebound and lift the rope high in the air. These little episodes did not seem to effect any one in the party so much as the *Leader* representative, who, though a man of great experience upon the water, could not seem to enjoy himself like the rest. The singing quartette, however, at every rebound, thought it great fun to serenade him with a portion of their favorite song—with a slight variation—

> Up from the *Lake* through the ether
> Swifter than eagles we soar to the sky.

Two or three times the sun came out, sending our craft nearly to the clouds again, and on one of these occasions two large schooners came in sight, tacking against the wind, not far from our path, when the *Leader's* sailorman became greatly excited: "Why don't they luff?" quoth he; "damn 'em, why don't they luff?" Then he drew a focus on them and repeated the query. (Cozad was winking hard.) "Hang out a signal, Professor; hang out a signal," he kept repeating.

"What for?" I demanded.

"Because it's always the thing to do when you are in distress," he replied. But the quartette was singing again louder than ever, and the schooners passed beyond speaking distance.

Later in the afternoon we were passing Point aux Pines, and still later Point au Rele reached out as an obstruction to our path, or as an hospitable welcoming coincident to our arrival in Canada. The rope was trailing as the balloon neared the shore, but lifted on reaching the land.

We crossed the shore line at seven o'clock, somewhat elated that night had not caught us while still over the water. An eight-hour study of this one element, and, incidentally, a three hundred mile ride without variation, was amply sufficient for pleasure purposes. How restful was the sight of the

fields, farmhouses and people. The drag-rope was allowed to trail again, which gave opportunity for brief conversation with the inhabitants as we passed their houses.

"What place is this?" asked the *Journal* man.

"Massea," was the response.

"How far are we from Detroit?"

"Twenty-eight miles."

"Are we going in the right direction for it?"

"No, you are going a little too far North."

"Thanks."

"You are welcome."

"Good night."

"Good night."

Night was coming on apace, and I called to some observers to catch our rope, and repeated the request, which simply set them to chattering among themselves in French. When I learned they could not understand us I called "Never mind," which brought the response: "Ah, pauvre hommes; pauvre hommes."

Two or three miles farther on was a man with an ox team, and when I made the same request of him he evidently understood, and started to run for the rope, but he was soon out of breath and shouted: "How the divvle can I catch it if yez doesn't hold up?"

By this time lights were sparkling in every direction. There was a wood ahead, which I determined to jump with a view of finding a quiet harbor behind it. On our right hand, a mile away was Lake St. Clair which we congratulated ourselves as having escaped very nicely. The drag-rope began trailing over the woods with little joggles now and then, and we had almost reached the farther side when a tall pine tree caught and held the rope. Our united strength was unequal to the task of getting the car back to the tree; but there was more than one way out of the difficulty, and the first one tried proved successful. Three heavy bags of sand, one after the other, were poured out into the woods below, and the rope was brought perpendicularly over the tree, when the rope was freed, and the balloon began a rapid ascent, which had to be checked by escaping gas. As luck would have it, we made a bee line for Lake St. Claire, the distance to which was too

short to allow of any maneuvers, and entered the clouds at the moment it was passing out over the Lake.

It was already night within the clouds, the faintest gray light remaining with us until we came out of it again. The water of the Lake below was never seen after entering the cloud, but, though we were shut in as closely as if embedded in a stone wall, we could hear the sound of splashing waves upon rocks or surf-bound shore, with little loss on account of distance, for the clouds, like a sounding board, gathered the swish, splash and wash of every wave so clearly that our course, lengthwise of the Lake, could be understood by the dashing water along the shore.

For hours our imaginations had full play. The concert was over. Singing would have been as much out of place as preaching. Thinking was easier, and possibly, if it was given voice it might have tallied with what my wife had to say one dark night when I landed with her in the top of an unusually high sugar tree, in a rainstorm: "Well, I want to know how you are going to get me out of this?"

Conjecture as to what was coming next certainly had full play, and I could only remind my fellow passengers that foreknowledge robbed genuine adventure of its keenest attraction. After all, it is more than likely that no one in the car tried harder than myself to work out the problem of our erratic voyage to its finish.

At last there came an ominous midnight stillness. We had left the lake behind us, and it was time to be getting out of the clouds. There was a straining of ears to catch the slightest sound, which caused a hysterical laugh when it came in the tinkle of a little bell, on a sheep, cow or goat. What matters it? Imagination could do the rest. But who would have guessed the next startling sound?—a prolonged blast filling the air and reverberating from the balloon above us! Lake Huron was in front of us. A light reflected from its water showed us the steamer whose siren had awakened the echoes of the night as it was entering Port Huron. We had no siren to announce our arrival from the land side; but if we had so decided, both landings could have been made in Port Huron at the same time. Landing, however, among houses at night was not like having a wharf to tie up to, and

we were not quite done yet. There was a river nearby, whose cloud reflections made it discernible in the general darkness, and over which the inland breeze bore the balloon away from the great lake back to dry land. How glad we should have been to have had a few hours of daylight; but, alas, inky darkness shrouded the earth below.

Six passenger balloon that left Cleveland and landed in Canada. From an old drawing showing King sliding down the drag rope—the last man to leave the airship.

"A great country this for woods as well as water," said our Geographer, Mr. Holden, which statement had to be taken and acted upon accordingly. Literally, the prospect could not be any darker if we stayed up all night; but there was a strong desire to make a landing before we got too far into the big woods.

In cases like this, one may observe different shades of blackness on the earth below. The forests are like jet; clear

fields a trifle lighter, and ploughed fields the lightest of all. Nevertheless, this was hunting in the dark. We wanted room—acres of it if possible—to avoid the trees; but in the present instance it seemed all of a piece, like the blackest velvet.

Some of the company ventured to doubt our ability to secure a landing place in this way; but at last there came what seemed to my trained eyes an opening in the woods. I quickly pulled the valve, and we settled down in the center of an open space, but did not land on terra firma as we expected to do; for a lonely monarch of the forest threw out its arms to receive us, and we were held firmly in its powerful embrace.

As there was little or no wind, and no sign of a storm, it was decided that we spend the night in our sky parlor, and although the bed wasn't built for six, we managed to settle down and get a few hours sleep.

At daybreak we took turns sliding down the drag-rope to the ground, and made our way to the house of a French Canadian, who, while his wife prepared a royal breakfast, helped us to dislodge the balloon car and deflate and pack the balloon, ready for another adventure in Cloudland.

Riding in the wagon of our host, on our way to the nearest railroad station, our aerial glee club suggested this was a good time for a vocal celebration, and soon the woods rang with the strains of:

Up from the earth through the ether,
Swifter than eagles we soar to the sky.
High over mountain and river;
Over forests and cities we fly.

RESONANCE THEORY OF SERIES NON-LINEAR CONTROL CIRCUITS.

BY

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The purpose of this paper is the development of a theory of the behavior of the series non-linear circuit based upon the resonance properties of such circuits. Simple series non-linear circuits are of special industrial importance in the design of relays, control circuits, and in the regulation of transmission lines. The theory here developed is applicable to series circuits possessing variable inductance, capacitance, and resistance. Because circuits possessing variable inductance present the greatest mathematical difficulty the theory is given in detail only for these circuits.

A formula for resonance is derived and procedure is given for the design of a circuit requiring a prescribed resonant voltage.

Experimental checks of the theory are given in Part III of the paper.

I. EXPERIMENTAL RESULTS.

Many experimental facts regarding these circuits appear in the literature. The most pertinent of these are as follows.

(*a*) *Volt-ampere Characteristic.*[1]—The volt-ampere characteristic of the circuit in Fig. 1 is shown in Fig. 2. The values of current and voltage displayed are root-mean-square values. In the regions *ab* and *cd* of the current response is approximately linear with the voltage; while in the region *bc* the current is critical with respect to the voltage, i.e., a slight increase in voltage produces a large increase in current. The value of the applied voltage for which this increase in current is greatest is called the resonant voltage.

[1] See numbered references in the bibliography.

(*b*) *Resistance Limited.*[1]—The maximum value of the current in the region *bc* is resistance limited, i.e., the peak of the current is given by $i = E/R$.

FIG. 1.

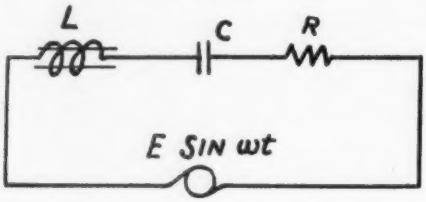
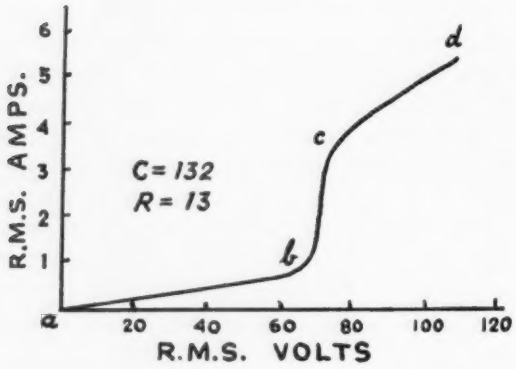


FIG. 2.



(*c*) *Phase Agreement.*—At resonant voltage, the voltage and current are approximately in phase. Where there is a difference in phase the current lags the voltage.

II. MATHEMATICAL THEORY.

B-H Function.—The B-H function is of course many-valued. But this function tends to become single-valued at large magnetizing forces for nicalloy, permalloy, and low-loss steels. Moreover, the numerical integration of the differential equations by means of the integraph shows that the graph obtained for the current in circuits of variable inductance is not changed by employing a single-valued B-H function. Accordingly, the equation of the magnetization curve is taken to be

$$H = ki = x - a_3x^3 + a_5x^5, \qquad (1)$$

where H = magnetizing force in Gilberts per square centimeter,

i = current in amperes,

$x = B/B_0$, where B is the flux-density in Gausses per square centimeter and B_0 is the slope of the magnetization curve at the origin. The quantities k, a_3, and a_5 are positive constants. More terms may be added in Eq. (1) if necessary.

Differential Equation.—The differential equation for the current in the circuit of Fig. (1) is

$$L(i)\frac{di}{d\tau} + Ri + \frac{1}{c}\int i\,d\tau = -E\cos\omega(\tau - \tau_0), \qquad (2)$$

which, by means of Eq. (1) and the substitution $\theta = \omega\tau$, becomes

$$M\frac{dx}{d\theta} + R(x - a_3x^3 + a_5x^5) + x_c\int(x - a_3x^3 + a_5x^5)d\theta = -Ek\cos(\theta - \theta_0), \qquad (3)$$

where

$M = k\omega NAB_0 10^{-8}$, c = capacitance in micro-farads,

$x_c = \frac{1}{\omega c}$, R = resistance in ohms,

$= 377$, A = area of cross-section of coil in sq. cms.,

τ = time in seconds, N = number of turns.

Differentiating Eq. (3) we obtain

$$M\frac{d^2x}{d\theta^2} + R(1 - 3a_3x^2 + 5a_5x^4)\frac{dx}{d\theta} + x_c(x - a_3x^3 + a_5x^5) = Ek\sin(\theta - \theta_0). \qquad (4)$$

To investigate the resonance between the applied voltage and the circuit it is necessary to determine the natural period of the circuit, i.e., it is necessary to integrate Eq. (4) for $E = 0$. This integration is accomplished in two steps. First Eq. (4) is integrated for $E = R = 0$ and then the solution is modified to take care of the resistance. Accordingly, the first equation to be integrated is

$$M\frac{d^2x}{d\theta^2} + x_c(x - a_3x^3 + a_5x^5) = 0. \qquad (5)$$

Performing a first integration of (5) we have

$$\left(\frac{dx}{d\theta}\right)^2 = \frac{a_5 x_c}{3M}\left(\frac{3}{a_5}C_0^2 - \frac{3}{a_5}x^2 + \frac{3a_3}{2a_5}x^4 - x^6\right), \qquad (6)$$

where

$$\left(\frac{dx}{d\theta}\right)^2 = \frac{x_c}{M}c_0^2 \qquad \text{for} \qquad x = 0.$$

The integral of Eq. (6) is hyperelliptic and we first obtain the period of the solution. The period of the solution is dependent, as in the elliptic case, on the amplitude of the flux.

The right side of Eq. (6) vanishes for only one real value of x, i.e., at the maximum value c of the flux. Accordingly, let (6) be written

$$\left(\frac{dx}{d\theta}\right)^2 = \frac{a_5 x_c}{3M}(c^2 - x^2) \times[x^4 + 2(b^2 - a^2)x^2 + (a^2 + b^2)^2] = 0, \qquad (7)$$

where

$$(a^2 + b^2)^2 = \frac{3}{a_5}\frac{c_0^2}{c^2}, \qquad (a^2 + b^2)^2 - 2(b^2 - a^2)c^2 = \frac{3}{a_5},$$

$$c^2 - 2(b^2 - a^2) = \frac{3a_3}{2a_5}, \qquad c_0^2 = c^2\left(1 - \frac{a_3}{2}c^2 + \frac{a_5}{3}c^4\right), \qquad (8)$$

$$a^2 = \frac{1}{2}\left(c^4 - \frac{3}{2}\frac{a_3}{a_5}c^2 + \frac{3}{a_5}\right)^{\frac{1}{2}} - \frac{1}{4}\left(c^2 - \frac{3}{2}\frac{a_3}{a_5}\right),$$

$$b^2 = \frac{1}{2}\left(c^4 - \frac{3}{2}\frac{a_3}{a_5}c^2 + \frac{3}{a_5}\right)^{\frac{1}{2}} + \frac{1}{4}\left(c^2 - \frac{3}{2}\frac{a_5}{a_5}\right).$$

Setting $x = cy$, $a/c = \beta$, and $b/c = \gamma$, Eq. (7) becomes

$$\left(\frac{dy}{d\theta}\right)^2 = A_0^2 c^4(1 - y^2)[(\beta^2 + \gamma^2)^2 + 2(\gamma^2 - \beta^2)y^2 + y^4], \qquad (9)$$

where

$$A_0^2 = \frac{a_5 x_c}{3M}. \qquad (10)$$

Period.—The solution of Eq. (9) possesses but one real period and this period T is equal to

$$T_c = \frac{2}{c^2 A_0}\int_{-1}^{+1} \frac{dy}{\{(1-y^2)[(\beta^2+\gamma^2)^2 + 2(\gamma^2-\beta^2)y^2 + y^4]\}^{\frac{1}{2}}}$$
$$= \frac{2}{c^2 A_0}(T_1 + T_2 + T_3),$$

where

$$T_1 = \int_{-1}^{-\beta} \frac{\{[(y-\beta)^2+\gamma^2][(y+\beta)^2+\gamma^2]\}^{-\frac{1}{2}}}{(1-y^2)^{\frac{1}{2}}}dy,$$
$$T_2 = \int_{-1}^{\beta} \frac{\{[(y-\beta)^2+\gamma^2][(y+\beta)^2+\gamma^2]\}^{-\frac{1}{2}}}{(1-y^2)^{\frac{1}{2}}}dy,$$
$$T_3 = \int_{\beta}^{1} \frac{\{[(y-\beta)^2+\gamma^2][(y+\beta)^2+\gamma^2]\}^{-\frac{1}{2}}}{(1-y^2)}dy.$$

Evidently $T_3 = T_1$. By the substitution

$$y = \frac{1-\beta}{2}\eta - \frac{(1+\beta)}{2},$$

T_1 is reduced to

$$T_1 = \int_{-1}^{+1} \frac{4(1-\beta)^{\frac{1}{2}}\{[1-2x_1h_1+h_1^2] \times [1-2x_2h_2+h_2^2](1-a_0\eta)\}^{-\frac{1}{2}}}{(3+\beta)^{\frac{1}{2}}\{[(1+3\beta)^2+4\gamma^2] \times [(1-\beta)^2+4\gamma^2](1+\eta)\}^{\frac{1}{2}}}d\eta, \quad (11)$$

where

$$h_1 = \frac{(1-\beta)\eta}{[(1+3\beta)^2+4\gamma^2]^{\frac{1}{2}}} = a_1\eta, \qquad x_1 = \frac{1+3\beta}{[(1+3\beta)^2+4\gamma]^{\frac{1}{2}}},$$
$$h_2 = \frac{(1-\beta)\eta}{[(1-\beta)^2+4\gamma^2]^{\frac{1}{2}}} = a_2\eta, \qquad x_2 = \frac{1-\beta}{[(1-\beta)^2+4\gamma^2]^{\frac{1}{2}}},$$
$$a_0 = \left(\frac{1-\beta}{3+\beta}\right).$$

Since $0 < h_i < 1$, $0 < x_i < 1$

$$(1-2x_ih_i+h_i^2)^{-\frac{1}{2}} = 1 + h_iP_1(x_i) + h_i^2P_2(x_i) + \cdots + h_i^nP_n(x_i) \quad (i = 1, 2),$$

where $P_1, P_2, \cdots, P_n$ are Legendre Polynomials. The expression $(1-a_0\eta)^{-\frac{1}{2}}$ is expansible in a rapidly convergent series. Substituting these expressions in Eq. (11) and carry-

ing out the integrations we have

$$T_1 + T_3 = 2\pi Q_0 S_0,$$

where

$$Q_0 = \frac{8\sqrt{2}\, a_0^{\frac{1}{2}}}{\pi\{[(1+3\beta)^2 + 4\gamma^2][(1-\beta)^2 + 4\gamma^2]\}^{\frac{1}{4}}},$$

$$S_0 = 1 - \frac{1}{3}\left(A_0' + \frac{1}{2}a_0\right) + \frac{7}{15}\left(\frac{3}{8}a_0^2 + \frac{1}{2}a_0 A_0' + A_2\right) + \cdots, \tag{12}$$

$$A_0' = a_1 x_1 + a_2 x_2,$$

$$A_2 = a_1^2 P_1(x_1) + a_1 a_2 P_1(x_1) P_1(x_2) + a_2^2 P_2(x_2),$$

$$A = c^2 A_0.$$

By means of the substitution $y = \beta\eta$ and the method employed in evaluating T_1 and T_3 the value of T_2 is

$$T_2 = \pi Q_1 S_1,$$

where

$$Q_1 = \frac{2\beta}{\pi(\beta^2 + \gamma^2)},$$

$$S_1 = 1 + \frac{1}{3}\left(2a_3^4 - a_3^2 + \frac{1}{2}\beta^2\right) + \frac{1}{10}\beta^2(2a_3^4 - a_3^2) + \cdots, \tag{13}$$

$$a_3 = \frac{\beta}{(\beta^2 + \gamma^2)^{\frac{1}{2}}}.$$

The series S_0 and S_1 are so rapidly convergent that two terms are sufficient in all computations.

Finally,

$$T_c = \frac{2\pi}{A}(Q_0 S_0 + Q_1 S_1) = \frac{2\pi}{A} Q(\beta^2, \gamma^2) = \frac{2\pi}{A} Q. \tag{14}$$

Integration of the Differential Equation for Zero Resistance.—Differentiating Eq. (9) with respect to θ, cancelling out $\frac{dy}{d\theta}$,

changing the independent variable from θ to t by means of the substitution $\theta = \frac{Qt}{A} = \frac{(1+\delta)}{A}t$, and writing $\frac{d^2y}{dt^2} = y''$ we have

$$y'' + (1+\delta)^2\{[(\beta^2+\gamma^2)^2 - 2(\gamma^2-\beta^2)]y + 2[2(\gamma^2-\beta^2) - 1]y^3 + 3y^5\} = 0. \quad (15)$$

Equation (15) by the aid of the identities of Eqs. (8) can be written

$$y'' + (1+\delta)^2\{[1 + a_{12}\mu^2 + a_{14}\mu^4]y + [a_{32}\mu^2 + a_{34}\mu^4]y^3 + a_{54}\mu^4 y^5\} = 0, \quad (16)$$

where

$$a_{12} = -2k_0^2, \qquad a_{14} = \left(1 - \frac{a_5}{3}\frac{c^6}{{c_0}^2}\right)k^4, \qquad a_{32} = 0,$$
$$a_{32} = 4k_0^2, \qquad a_{34} = -\frac{2}{3}a_5\frac{c^6}{{c_0}^2}k^4, \qquad a_{54} = \frac{a_5 c^6 k^4}{{c_0}^2}, \quad (17)$$
$$k_0^2 = \gamma^2 - \beta^2, \qquad k^2 = \beta^2 + \gamma^2.$$

and μ is a parameter to guide the integration. The parameter μ is subsequently set equal to unity. If the core of the reactor is any kind of iron with a sharp $B - H$ curve the ranges of the constants employed either directly or indirectly turn out to be

$$2 < c < 5, \qquad 2000 < B_0 < 5000, \qquad .4 < \beta < .7,$$
$$.4 < \gamma < .8, \qquad .3 < a_3 < 3, \qquad .01 < a_5 < .5,$$
$$0 < k_0 < 1, \qquad 0 < k < 1, \qquad -1 < \delta < 1.$$

Now the solution of Eq. (16) is periodic of period T is θ of or period 2π in t. This solution is now obtained. It follows from a theorm of Cauchy[2] that there exists a solution of Eq. (16) of the form

$$y = y_0 + y_2\mu^2 + y_4\mu^4 + \cdots, \quad (18)$$

which converges for μ^2 sufficiently small, or which converges for $\mu^2 = 1$ provided both k_0^2 and k^2 are sufficiently small. Write

$$\delta = \delta_2\mu^2 + \delta_4\mu^4 + \cdots. \quad (19)$$

Substituting Eqs. (18–19) in Eq. (16) and equating like powers

of μ^2 we obtain

$$\begin{aligned} &y_0'' + y_0 = 0, \\ &y_2'' + y_2 + 2\delta_2 y_0 + a_{12}y_0 + a_{32}y_0^3 = 0, \\ &y_4'' + y_4 + (\delta_2^2 + 2\delta_4)y_0 + a_{14}y_0 + a_{34}y_0^3 + a_{54}y_0^5 \\ &\quad + a_{12}y_2 + 3a_{32}y_0^2 + 2\delta_2(a_{12}y_2 + a_{32}y_0^3) = 0, \\ &\quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{20}$$

for the determination of $y_0, y_2, y_4, \cdots$.

To determine the initial conditions in t, substitute

$$\theta = \frac{(1 + \delta)t}{A}$$

in Eq. (9) and let $y = 0$. Then

$$y'(0) = (1 + \delta)(\beta^2 + \gamma^2) = (1 + \delta_2\mu^2 + \delta_4\mu^4 + \cdots)A_{11} \tag{21}$$

from which $y_0'(0) = A_{11}$. The solution of the first of Eqs. (20) is

$$y_0 = A_{11} \sin t. \tag{22}$$

When this value of y_0 is substituted in the second of Eqs. (20) it follows that the solution for y_2 can not be periodic unless δ_2 is so chosen that the linear terms in y_0 vanish. From this condition

$$\delta_2 = \left(1 - \frac{3}{2}A_{11}^2\right)k_0^2.$$

The initial condition for y_2 is $y_2'(0) = \delta_2 A_{11}$. Thus the solution for y_2 is

$$y_2 = A_{21} \sin t + A_{23} \sin 3t, \tag{23}$$

where

$$A_{21} = A_{11}k_0^2\left(1 - \frac{15}{8}A_{11}^2\right), \qquad A_{23} = \frac{1}{8}k_0^2A_{11}^3.$$

When y_0 and y_2 are substituted in the third equation of (20) the coefficient of the linear terms in y_0 must vanish in order that y_4 be periodic in t. Thus the δ's and y's may be found sequentially as far as desired.

Due to the arrangement of the problem the maximum value of y is unity and the maximum value of the instantaneous flux is B_0c. The flux B is given by the relation $B = B_0cy$. Substitution in Eq. (1) gives the instantaneous value of i.

Integration of the Equation with Small Resistance.—The solution of Eq. (4) for $E = 0$, is of course, not periodic. The solution decays; its period, increasing and its amplitude decreasing as c diminishes until the circuit has become linear. (See Eq. 14.) The solution after the circuit has become linear of course, is a damped sinusoid of fixed period. But we are interested eventually in those cases where the applied voltage $E \sin (\theta - \theta_0)$ maintains in the steady-state the maximum value B at B_0c. From physical considerations it is obvious that the time of oscillation is increased by resistance. From Eq. (4) it is evident that the effect of resistance on the flux is a non-linear one.

It is now desired to obtain the natural period of the circuit with resistance when the circuit is operated at maximum flux. B_0c. By means of Eqs. (8) and the relation

$$\theta = \frac{Q}{A}(1 + \delta)t,$$

Eq. (4) can be transformed to

$$y'' + r(1 + 3b_3y^2 + 5b_5y^4)y' + (1 + \delta)^2(b_1'y + b_3'y^3 + b_4'y^5) = 0, \quad (24)$$

where

$$r = \frac{R}{x}AQ(1 + a_{12}\mu^2 + a_{14}\mu^4) = \frac{R}{x_c}AQb_1',$$

$$b_1' = k^4 - 2k_0^2, \qquad b_3' = 2(2k_0^2 - 1), \qquad b_5' = 3, \quad (25)$$

$$b_3 = \frac{b_3'}{b_1'}, \qquad b_5 = \frac{b_5'}{b_1'}.$$

Equation (24), written in the normal form, is

$$y_1' = y_2,$$
$$y_2' = -r(1 + 3b_3y^2 + 5b_5y^4)y_2 - (1 + \delta)^2(b_1'y_1 + b_3'y_1^3 + b_5'y_1^5). \quad (26)$$

The solution of system (26) for $r = 0$ is

$$y = (A_{11} + A_{21}) \sin t + A_{23} \sin 3t + \cdots. \quad (27)$$

On passing to numerical results (See section III) y is practi-

cally sinusoidal. Thus let the solution of Eqs. (26) for $r = 0$ be

$$\begin{aligned} y_1 &= u \sin (t + v), \\ y_2 &= u \cos (t + v). \end{aligned} \tag{28}$$

In completing the solution of (26) we shall employ the method of variation of parameters,[3] i.e., the equations

$$\begin{aligned} \frac{\partial y_1}{\partial u}\frac{du}{dt} + \frac{\partial y_1}{\partial v}\frac{dv}{dt} + \frac{\partial y_1}{\partial t} &= y_2, \\ \frac{\partial y_2}{\partial u}\frac{du}{dt} + \frac{\partial y_2}{\partial v}\frac{dv}{dt} + \frac{\partial y_2}{\partial t} &= y_2'. \end{aligned} \tag{29}$$

Equations (29) yield

$$\begin{aligned} u' &= -r(1 + 3b_3y_1^2 + 5b_5y_1^4)\, u \cos^2 (t + v), \\ v' &= r(1 + 3b_3y_1^2 + 5b_5y_1^4) \sin (t + v) \cos (t + v). \end{aligned} \tag{30}$$

By substituting Eqs. (28) in (30) and carrying out the expansions we obtain

$$\begin{aligned} u' = -r[&e_0 + e_2 \cos (t + v) \\ &+ e_4 \cos 4(t + v) + e_6 \cos 6(t + v)], \\ v' = r[&f_2 \sin 2(t + v) \\ &+ f_4 \sin 4(t + v) + f_6 \sin 6(t + v)], \end{aligned} \tag{31}$$

where

$$e_0 = \frac{1}{2}u + \frac{3}{8}b_3u^3 + \frac{5}{16}b_5u^5, \qquad f_2 = \frac{1}{2} + \frac{3}{4}b_3u^2 + \frac{25}{32}b_5u^4,$$

$$e_2 = \frac{1}{2}u - \frac{5}{32}b_5u^5, \qquad f_4 = -\frac{3}{8}b_3u^2 - \frac{5}{8}b_5u^4,$$

$$e_4 = -\frac{3}{8}b_3u^3 - \frac{5}{16}b_5u^5, \qquad f_6 = \frac{5}{32}b_5u^4,$$

$$e_6 = \frac{5}{32}b_5u^5.$$

By Cauchey's theorem [2] there exists a solution of Eqs. (31) as a power series in r. Referring to Eqs. (27–29) it is clear that $u = (A_{11} + A_{21}) = e$ and $v = 0$ for $r = 0$. Accordingly, write

$$\begin{aligned} u &= e_0 + u_1r + u_2r^2 + \cdots, \\ v &= v_1r + v_2r^2 + \cdots. \end{aligned} \tag{32}$$

Now r (See section III), for control circuits, is very small. Consequently, v is small. Expanding $\cos n(t + v)$ $(n = 2, 4, 6)$ in Eqs. (31) as a power series in v, substituting Eqs. (32) in (31), and equating, in the resulting equations, the coefficients of like powers of r we obtain

$$\begin{aligned} u_0' &= 0, \\ v_1' &= f_2 \sin 2t + f_4 \sin 4t + f_6 \sin 6t, \\ u_1' &= -(e_0 + e_2 \cos 2t + e_4 \cos 4t + e_6 \cos 6t), \\ v_2' &= (g_2 \sin 2t + h_4 \sin 4t + h_6 \sin 6t)u, \\ &\quad + 2v_1(f_2 \cos 2t + 2f_4 \cos 4t + 4f_6 \cos 6)t, \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{33}$$

where

$$g_2 = \left(\frac{3}{2}b_3 + \frac{25}{8}b_5e^2\right)e,$$

$$g_4 = -\left(\frac{3}{4}b_3 + \frac{5}{2}b_5e^2\right)e,$$

$$g_6 = \frac{5}{8}b_5e^3.$$

Equations (33) are solved sequentially subject to the initial conditions $u_0 = e$, $u_i = v_i = 0$ for $t = 0$, $i = 1, 2, \cdots$. The solutions are

$$\begin{aligned} u_0 &= e, \\ v_1 &= \frac{1}{2}\Big[f_2(1 - \cos 2t) + \frac{1}{2}f_4(1 - \cos 4t) \\ &\qquad + \frac{1}{3}f_6(1 - \cos 6t)\Big], \\ u_1 &= -\left(e_0t + \frac{1}{2}e_2 \sin 2t + \frac{1}{4}e_4 \sin 4t + \frac{1}{6}e_6 \sin 6t\right), \\ v_2 &= \frac{1}{2}e_0t\left(g_2 \cos 2t + \frac{1}{2}g_4 \cos 4t + \frac{1}{3}g_6 \cos 6t\right) \\ &\quad - \frac{1}{4}t\left(g_2e_2 + \frac{1}{2}g_4e_4 + \frac{1}{3}g_6e_6\right)\frac{1}{2}(f_2^2 + f_4^2 + f_6^2)t, \end{aligned} \tag{34}$$

where the f's, e's, and g's of equations (34) are the same symbols previously defined but with u replaced by e.

Substituting Eqs. (34) in (32) and (32) in turn in (28) the solution of Eqs. (24) as far as the terms in r^2 is obtained. The

immediate objective is to find the period of a half-cycle when the applied voltage maintains the circuit operating at maximum flux B_0C. It is then necessary to solve $y_1(t) = 0$ for t. Evidently, y_1 vanishes for $t + v_1(t)r + v_2(t)r^2 + \cdots = \pi$. Solving this equation by Newton's method (an approximate root is π) we obtain

$$t = \pi\left(1 + \frac{r^2}{8}\delta_0\right), \tag{35}$$

where

$$\delta_0 = 1 + 2.24b_3e^2 + (2.08b_5 + 1.4b_3^2)e^4 + .36b_3b_5e^6 + 1.4b_5^2e^8. \tag{36}$$

Finally, by means of the transformation $\theta = \frac{Q}{A}t$ and Eqs. (14) and (35) the period, taking into account the resistance, is

$$T_{cr} = \frac{2\pi}{A}Q\left(1 + \frac{r^2}{8}\delta_0\right). \tag{37}$$

The period in θ of the applied voltage (Eq. 4) is 2π. The condition for the circuit to be in resonance with the applied voltage is $T = 2\pi$. Substituting this value in Eq. (37), neglecting the term containing r^4, and solving for x_c we obtain

$$x_{cr} = \frac{3MQ^2}{2c^4a_5}\left(1 + \sqrt{1 + \frac{1}{9}\delta_0c^8a_5^2b'^2_1M^{-2}R^2}\right). \tag{38}$$

The final results are: (a) proof of the physical principle that the sudden increase in current in the region bc Fig. 2 is due to the circuit being in resonance with the applied voltage, (b) formula (37) for the natural period of such a circuit, (c) formula (38) giving the amount of capacitative reactance required to produce resonance at a prescribed voltage.

III. EXPERIMENTAL CHECKS OF THE THEORY.

The data for the reactor employed is

Area of center lag times stacking factor = 4.64 cms².,
Mean length of path = 13.5 cms.,
Number of turns = 430.
Type of steel – $X5$
$k = 25$.

In Tables I–IV the saturation curve of the reactor is used. In Tables V–IX the saturation curve of $X5$ steel is used. In computing the mathematical approximation to the saturation curve B_0 is the slope of the line L in Figs. 3, 4, and 5. To determine a_3 and a_5 in Eq. (1) two points are taken on the saturation curve; one above, the other below the knee.

TABLE I.

Transformer Saturation Curve—Damping Neglected—Above Knee.

$M = 781$, $B_0 = 4100$, $a_3 = .62$, $a_5 = .14$.

Case	R	E_0	x_{ct}	H	c	β	γ	Q	x_c	T_c
1.	13	70	20.1	188.6	4.5	.50	.76	.69	19	6.09
2.	17	68	26.1	140.4	4.15	.51	.75	.65	23.6	6.28
3.	23.3	69	39.1	105	3.96	.51	.73	.72	35.4	6.09
4.	72.5	61	63.2	29	3.24	.53	.71	.65	63.7	6.28

TABLE II.

Transformer Saturation Curve—Damping Neglected—Below Knee.

$M = 781$, $B_0 = 4100$, $a_3 = .62$, $a_5 = .14$.

Case	R	E_0	x_{ct}	H	c	β	γ	Q	x_c	T_c
1.	72.5	48	126	24	3.02	.53	.67	.69	114	5.65
2.	107	39	190	13.2	2.71	.59	.64	.78	186	5.90

TABLE III.

Transformer Saturation Curve—Damping Included—Above Knee.

$M = 781$, $B_0 = 4100$, $a_3 = .62$, $a_5 = .14$.

Case	e	k_0^2	k^4	A	b_1'	r^2	$(1+(r^2/8)\delta_0)$	x_{cr}	T_{cr}
1.	.76	.33	.69	.72	.03	.0001	1.025	19.76	6.17
2.	.77	.30	.67	.65	.07	.0002	1.009	24.31	6.33
3.	.74	.26	.61	.74	.09	.0008	1.018	37.70	6.23
4.	.76	.24	.61	.65	.13	.0039	1.055	69.40	6.59

TABLE IV.

Transformer Saturation Curve—Damping Included—Below Knee.

$M = 781$, $B_0 = 4100$, $a_3 = .62$, $a_5 = .14$.

Case	e	k_0^2	k^4	A	b_1'	r^2	$(1+(r^2/8)\delta_0)$	x_{cr}	T_{cr}
1.	.86	.18	.69	.77	.33	.01	1.045	110.5	5.90
2.	.77	.06	.58	.81	.46	.029	1.054	201	6.22

The slope of the saturation curve of $X5$ steel varies through a rather wide range between the origin and the knee. Tables VIII and IX show the results when B_0 is taken to be the average slope over this interval. The results indicate that B_0 should be taken as the slope of L.

TABLE V.

X − 5 Steel Saturation Curve—Damping Neglected—Above Knee.

$M = 937$, $B_0 = 5000$, $a_3 = 1.58$, $a_5 = .39$ for cases 1, 2, 3. $a_3 = .92$, $a_5 = .198$ for case 4.

Case	R	E_0	x_{ct}	H	c	β	γ	Q	x_c	T_c
1.	13	70	20.1	188	3.7	.54	.69	.71	19.9	6.22
2.	17	68	26.1	140	3.50	.53	.68	.70	22	5.27
3.	23.3	69	39.1	105	3.32	.53	.64	.73	40	5.52
4.	72.5	48	126	24	2.94	.51	.61	.84	132	6.28

TABLE VI.

X − 5 Steel Saturation Curve—Damping Neglected—Below Knee.

$M = 937$, $B_0 = 5000$, $a_3 = .49$, $a_5 = .12$.

Case	R	E_0	x_{ct}	H	c	β	γ	Q	x_c	T_c
1.	107	39	190	13	286	62.8	.87	.79	218	6.84
2.	155	46	190	10.4	2.8	62	.86	.80	219	6.84

TABLE VII.

X − 5 Steel Saturation Curve—Damping Included—Above Knee.

$M = 937$, $B_0 = 5000$, a_3 and a_5 same as Table V.

Case	e	k_0^2	k^4	A	b_1'	r^2	$(1+(r^2/8)\delta_0)$	x_{cr}	T_{cr}
1.	.77	.19	.59	.71	.21	.0046	1.030	20.5	6.49
2.	.74	.18	.56	.73	.20	.0040	1.022	23.1	6.10
3.	.69	.13	.48	.80	.22	.0058	1.017	42.0	5.85
4.	.63	.11	.40	.81	.18	.0049	1.015	133.2	6.60

TABLE VIII.

X − 5 Steel Saturation Curve—Damping Neglected—Above Knee.

$M = 770$, $B_0 = 4040$, $a_3 = .5$, $a_5 = .13$.

Case	R	E_0	x	H	c	β	γ	Q	x_c	T_c
1.	13	70	20.1	188	4.51	.50	.76	.63	17.8	5.97
2.	17	68	26.1	140	4.22	.52	.78	.60	20	5.65
3.	23.3	69	39.1	105	3.98	.51	.76	.63	30.3	5.53

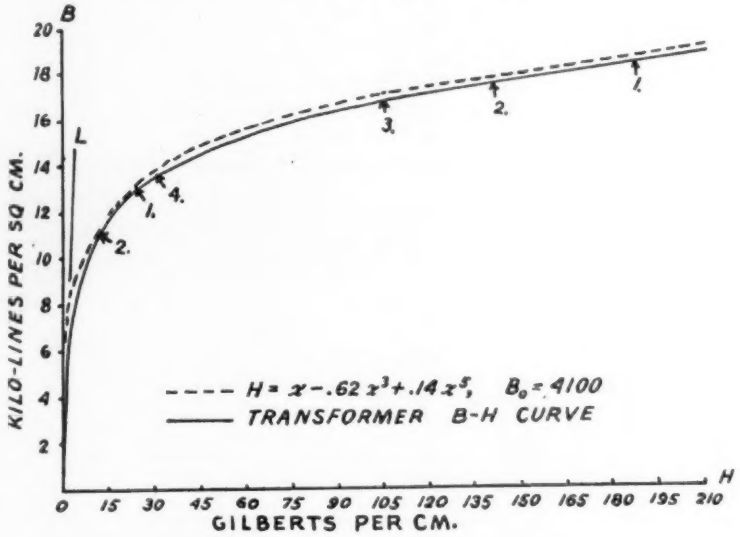
TABLE IX.

X − 5 Steel Saturation Curve—Damping Neglected—Below Knee.

$M = 770$, $B_0 = 4040$, $a_3 = .42$, $a_5 = .06$.

Case	R	E_0	x	H	c	β	γ	Q	x_c	T_c
1.	72	61	63	29	3.9	.54	.67	.73	56	5.25
2.	72	48	126	24	3.7	.54	.62	.82	156	6.15
3.	107	39	190	13	3.4	.52	.52	1.09	348	8.16
4.	155	46	190	10.4	3.3	.56	.56	.96	301	7.84

FIG. 3.



From experimental result (b) of Part I there is the relation $H = ki = \frac{kE}{R} = \frac{\sqrt{2}\,kE_0}{R}$ (root-mean-square). The value of B at resonance corresponding to this value of H is read from the mathematical approximation to the saturation curve. (The maximum B is indicated by arrows for the various circuits on Figs. 3, 4, 5). The value of c is $c = B/B_0$. The values of β, γ, Q, and T_c are computed from Eqs. (8), (12), and (14). In Tables III, IV, and VII A, b_1', and r are computed from Eqs. $A = c^2\left(\frac{a_5 x_c}{3M}\right)^{\frac{1}{4}}$ and Eqs. (25), and δ_0 from Eq. (36). The values of x_{cr} and T_{cr} are given by Eqs. (37–38). In computing T_{cr} the test value x_{ct} is used in computing A.

FIG. 4.

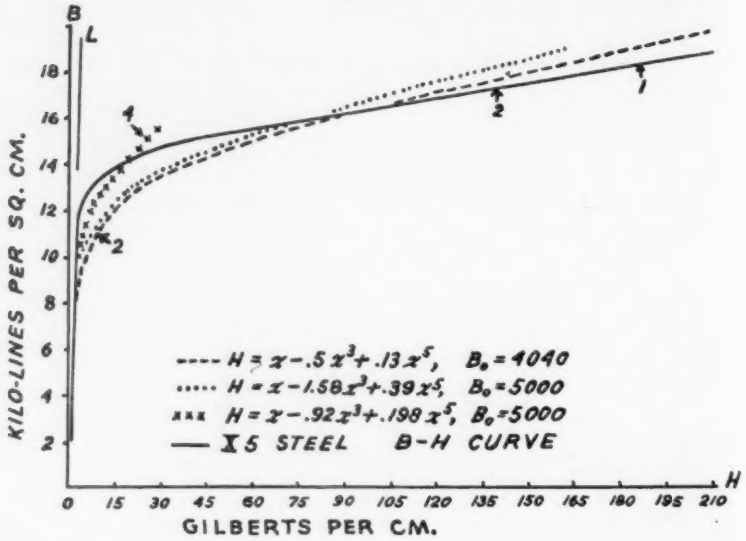
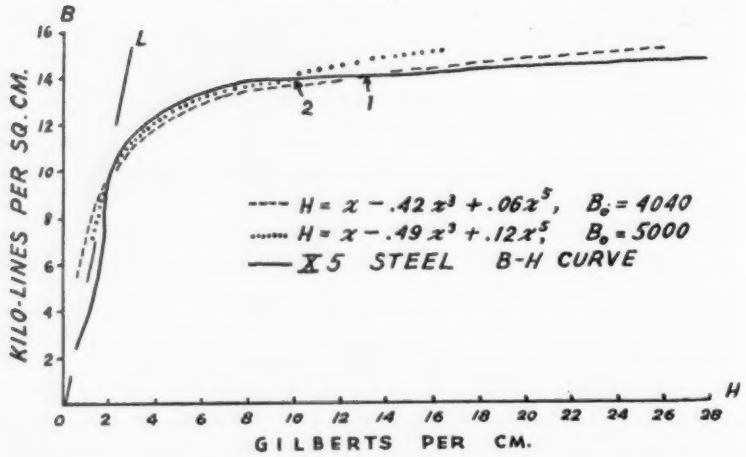


FIG. 5.



CONCLUSIONS.

The accuracy of the theory is observed by comparing in the tables x_c and x_{cr} with the test value x_{ct} and T_c and T_{cr} with 2π the period of the applied voltage. In control circuits, since a large jump in current is desired, the circuit should come into

resonance with the applied voltage for a value of B above the knee of the saturation curve. For these cases in Tables III and VII the average error in the computed period is .24 percent. For these practical cases it is immaterial whether the saturation curve of the transformer or of the steel is used in computing x.

Finally, it may seem that for greater values of c (and E) the circuit would cease to be in resonance, i.e., that the curve in Fig. 2 would have a maximum value. But as c is increased beyond resonance the period remains almost constant. For example, in case 1 Table I when $c = 4.7$ (almost complete saturation) $T_c = 5.90$ while for $c = 4.7$, $T_c = 6.09$. Thus the circuit remains in resonance as c increases beyond the resonant voltage.

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Rare Sugar Produced Cheaply by New Method.—Sorbose, a rare sugar which can be used in making synthetic vitamin C and which formerly sold at $500 a pound, can now be produced at 75 cents a pound by a new method developed by the United States Department of Agriculture. Sorbose, chemically classed as a ketose sugar, was discovered more than 40 years ago, but because of the lack of a practical method of manufacture it has remained a laboratory curiosity. Its structure makes it especially suitable as starting material for the chemical synthesis of vitamin C (ascorbic acid). The ease with which it can now be prepared should make it available for other uses. In the new method sorbose is produced by the bacterial fermentation of sorbitol, an alcohol made from pure corn sugar. The success of the methods depends on the use of a new type of rotatory fermenter in which submerged cultures instead of surface growths of the bacteria are used. The yield is high, around 95 per cent., and the whole process can be completed in 24 hours. The product is purified by the same methods used in the manufacture of sugar. The short time required and the large yields produced by the new method should make it possible to manufacture sorbose on a practical basis. Semiplant scale production of this new product at the Bureau of Chemistry and Soils agricultural by-products laboratory in coöperation with Iowa State College of Ames, indicates that the new method is commercially feasible.

R. H. O.

THE VELOCITY OF SOUND IN AIR.

BY

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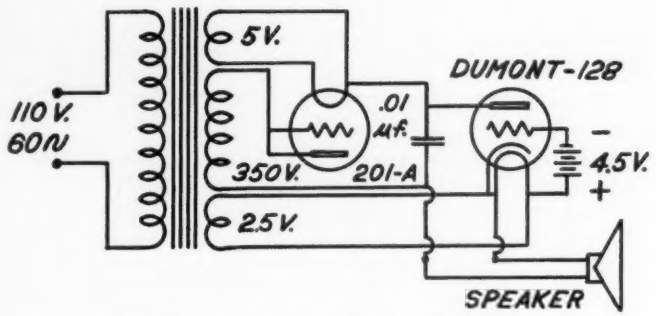
The velocity of sound in free air has been measured over long distances by means of explosives and chronometers.[1] With modern electrical devices it is possible to find this velocity over short distances in a laboratory room. It is necessary, however, to cover the walls with absorbing material in order to avoid echo effects. In the apparatus of Fig. 1

FIG. 1.



The electron tube device for producing sound pulses.

an electron tube is connected in the circuit in such a way that sixty short impulses per second are given to the loud speaker. To the ear this sounds very much like a sixty cycle note. The pulse device is very similar to other arrangements which have been used in ionospheric measurements.[2] The chief difference lies in the fact that the condenser discharge is allowed to pass through a loud speaker instead of a resistor. The timing of the impulses is very uniform due to the fact

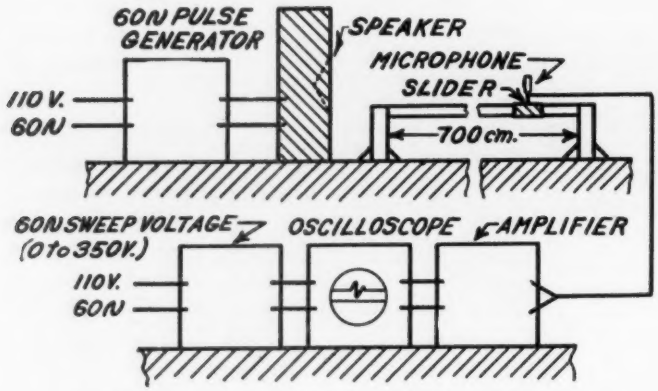
[1] Wood, "A Textbook of Sound" (Macmillan), p. 234; Miller, Sound Waves, Their Shape and Speed, Macmillan, 1937.

[2] Colwell, R. C., Friend, A. W. and Hall, N. I., *R. S. I.*, 7, 420 (1934); Colwell, R. C., and Friend, A. W., *Phys. Rev.*, **50**, 632 (1936).

that it is exactly synchronized with the 60 cycle power line. The sound pulses are picked up by a microphone which converts them into electrical pulses. After amplification they are observed upon a cathode ray oscilloscope. The diagram of Fig. 2 shows the connections of the apparatus. A variable high voltage 60 cycle A.C. wave is used for the horizontal sweep of the oscilloscope.

The measurements are made as follows: (1) With the current turned on so that the impulse from the microphone produces a vertical pattern on the oscilloscope screen, the microphone is moved along the bench to the end nearest the loudspeaker; (2) the position is adjusted until the peak pulse

FIG. 2.



The loud speaker, the microphone pickup and the sweep circuit.

falls on an index line at the center of the screen; (3) the position of the microphone is marked on the bench; (4) the microphone is then moved along the bench away from the loud speaker to a distance of roughly five and one half meters (approximately 18 feet). It is then accurately adjusted in position until the pulse again falls on the central line of the oscilloscope screen. This represents a position of the microphone at which the sound impulse arrives one cycle later than at the original position. This represents a time interval of one sixtieth of a second; (5) the distance between the two positions of the microphone is measured and this distance multiplied by sixty gives the velocity of sound.

The same procedure will apply when sweeps other than the 60 cycle are used. It is possible for instance to measure the velocity over a distance of 40 centimeters with a 1000 cycle sweep or over 12 centimeters with a 3000 cycle sweep. On the whole, however, the best results have been obtained over the longer distances (five to six meters). The reason for this is that a single index line is used at the center of the oscillograph screen and that the horizontal sweep velocity may be increased to 10,000 centimeters per second on a five-inch cathode ray tube even with the 60 cycle sweep.

There are five possible sources of error each of which may be made very small. The accuracy of the time measurement on the screen is within 10^{-5} seconds for a 60 cycle wave. This is possible only if the timing pulse is of a sharp peaked type. By using higher sweep frequencies, the accuracy may be extended to 10^{-6} seconds. The second source of error lies in the accuracy of the timing frequency. With standard frequencies obtained from a quartz crystal oscillator in conjunction with a multivibrator, this error may be reduced to 5 parts in a million. When the 60 cycle power line frequency is used, the accuracy will not be better than 0.3 per cent. for any one reading but the average of a series of readings will reduce this error to about 0.01 per cent. The third error arises in the measurement of the distance through which the microphone has been moved. With precision methods this distance also can be measured to within one part in a million. The fourth source of error is due to echo effects which distort the pulse. These can be averted by covering all reflecting surfaces with a sound absorbing material such as woolen blankets, cloth, etc. The fifth error is caused by temperature effects. All the air in the room must be at the same temperature. Wind currents and layers of air at different temperatures which cause trouble in outdoor experiments are entirely eliminated in the type of measurement outlined in this article.

The measurements given here were made rather to test out the method than to obtain accurate measurements of sound velocities. The average, however, agrees very well with the results arrived at by other methods. In each run of ten, the microphone was moved slightly (a few centimeters) each time. This produced a displacement of the pulse away

from the index line. It was brought back to zero by slightly changing the phase of the 60 cycle current imposed upon the sweep circuit. In the separate runs, the loud speaker was displaced several centimeters between each run of ten and the resulting displacement on the screen was allowed for by moving the microphone until the pulse returned to the index line.

The results given in Table I were obtained with a time

TABLE I.
Velocity of Sound in Air at 0° C.

Distance.	Distance.	Distance.	Distance.	Distance.
574.5 cm.	579.4 cm.	577.3 cm.	577.6 cm.	578.5 cm.
576.8	579.3	574.7	577.8	576.2
577.4	579.3	576.3	577.2	577.2
576.3	580.1	577.3	576.6	577.3
578.7	578.4	577.5	577.4	578.2
575.1	576.9	576.8	576.6	577.3
575.3	578.1	577.4	576.9	575.9
576.1	578.3	577.8	578.0	577.1
576.9	579.4	577.2	577.3	576.9
576.7	577.8	576.7	577.5	576.9
576.38 Av.	578.70 Av.	576.90 Av.	577.29 Av.	577.15 Av.
$t = 24.4°$ C.	$t = 26.2°$ C.	$t = 24.6°$ C.	$t = 24.9°$ C.	$t = 24.4°$ C.
$V_{24.4} = 345.83$	$V_{26.2} = 347.22$	$V_{24.6} = 346.14$	$V_{24.9} = 346.37$	$V_{24.4} = 346.29$
$V_0 = 331.36$	$V_0 = 331.64$	$V_0 = 331.52$	$V_0 = 331.58$	$V_0 = 331.79$

TABLE I.—*Continued.*

Distance.	Distance.	Distance.	Distance.	Distance.
578.2	575.6	577.0	577.6	577.1
577.0	579.5	577.8	576.5	574.8
576.5	577.8	576.0	577.5	578.4
577.5	576.0	577.5	576.7	577.3
578.5	573.2	574.2	575.6	576.2
580.5	576.2	575.9	577.5	578.0
578.0	575.8	577.4	576.5	577.8
575.5	575.9	575.3	576.8	576.6
577.0	576.2	578.2	575.8	576.3
576.0	575.4	575.6	574.6	575.8
577.47 Av.	576.08 Av.	576.49 Av.	576.51 Av.	576.83 Av.
$t = 24°$ C.	$t = 24°$ C.	$t = 24.2°$ C.	$t = 24.4°$ C.	$t = 24.4°$ C.
$V_{24} = 346.48$	$V_{24} = 345.6$	$V_{24.2} = 345.89$	$V_{24.4} = 345.91$	$V_{24.4} = 346.1$
$V_0 = 331.62$	$V_0 = 331.34$	$V_0 = 331.53$	$V_0 = 331.42$	$V_0 = 331.63$

interval of one sixtieth of a second. They were reduced to the standard temperature 0° C. by use of the formula

$$V_t = V_o\sqrt{1 + \frac{t}{273}}.$$

The average velocity for the one hundred measurements given in the table is 331.54 meters/sec.

Measurements were also made at very much smaller time intervals over correspondingly smaller distances. The results are given in Table II. These tables show very plainly that more uniform results are obtained when a long base line (5 to 6 meters) is used.

TABLE II.

Velocity of Sound in Air at 0° C.

Time Interval 1/3000 seconds.	Time Interval 1/1500 seconds.	Time Interval 1/1000 seconds.
11.4 cms.	23.2 cms.	34.4 cms.
11.8	23.6	34.8
11.3	23.5	34.4
11.4	23.5	34.3
11.9	23.1	34.7
11.3	23.0	34.3
11.7	23.3	34.8
11.4	23.2	34.7
11.5	23.1	34.8
11.3	23.3	34.4
$t = 27.2°$ C.	$t = 27.2°$ C.	$t = 25°$ C.
$V_0 = 329.32$ m./sec.	$V_0 = 333.02$ m./sec.	$V_0 = 330.72$ m./sec.

Whistles in the Air.—According to the News Edition of *Industrial and Engineering Chemistry*, Vol. 16, No. 3, CHESTER W. RICE of the General Electric Co. has shown that gases like hydrogen, nitrogen, oxygen, and air can be converted into liquid form more quickly by making them whistle. Gases are liquefied by removing heat energy from them. This is done by compressing the gas to a pressure of 3000 pounds per square inch, or 200 times atmospheric pressure, and then allowing it to expand suddenly after cooling with ice. The compressed gas then passes through a series of tubes into a liquefying chamber where the pressure is suddenly released through a throttle valve in the form of a whistle. This whistle permits a further escape of heat energy and thereby adds a marked cooling effect, increasing the efficiency of equipment now in use. The whistle can be set at a pitch that will convert the greatest amount of heat energy into sound energy. To be effective, the sound energy must be conveyed away from the liquefying chamber.

R. H. O.

Dehydrate Oil with High Potential.—(*Electrical World*, Vol. 109, No. 7.) Applying a recent development of the Petroleum Rectifying Co. of California, the Union Oil Co. is dehydrating crude oil at its Poso Creek Plant by subjecting the emulsion to a high potential field. This produces agglomeration through ionization of water particles and their envelopes and permits treating 2000 bbl. of emulsion with but 40 kw.-hr. of energy. The process consists essentially of two steps: First, the rupture of the water particles by application of a potential of from 5000 to 10,000 volts per inch; second, the agglomerization of the freed water particles into sizeable droplets which settle by gravity. The field is applied in one tank, and settling takes place in a second, dry oil being removed from the top.

R. H. O.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

NOTE ON THE VARIATION OF THE PRODUCTION OF BURSTS OF IONIZATION WITH THICKNESS.

BY

C. G. MONTGOMERY and D. D. MONTGOMERY,

Bartol Research Foundation of The Franklin Institute, Swarthmore, Penna.

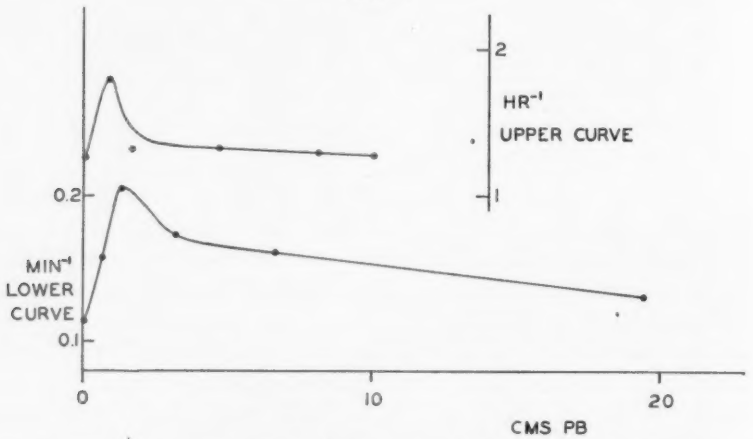
R. T. Young [1] has recently reported some experiments on the rate of occurrence of bursts of ionization in a small ionization chamber as a function of the thickness of the lead placed over the chamber. Young carried out observations at sea level and at two higher elevations. The chamber was spherical, 7.6 cm. in diameter, made of iron 1 mm. thick, and filled with argon at a pressure of 15 atmospheres. It was surrounded on the sides by a cylindrical shield 6 cm. thick, and above the chamber were placed plates of lead of various thicknesses built up in the form of a rough cone whose half angle was 41 degrees. The frequencies of bursts of ionization produced by groups of ten to twenty rays passing simultaneously through the chamber were measured. A striking feature of Young's observations is the large number of bursts which occurred when 10 cms. or more of lead were placed over the chamber. The data furnished by this experiment are of considerable importance in interpreting the interrelations and effects of the various components of the cosmic radiation. It is not certain, however, whether the bursts observed when large thicknesses of material were placed over the chamber really came from the thick layer of lead, or whether they originated in the thinner side shields. It was therefore decided to perform a supplementary experiment at sea level without the 6 cm. side shields, in order to be certain that the bursts of ionization were not caused by showers starting in these shields.

The experiment was performed using an ionization cham-

[1] R. T. Young, *Phys. Rev.*, **52**, 559 (1937).

ber of the same dimensions, and a similar type of vacuum tube electrometer was employed to record the bursts, as in Young's experiment. Lead shot was placed over the chamber in a conical can of sheet iron, the half angle of the cone being 21 degrees. The apparatus was located on the top floor of the Bartol Foundation Laboratory. The rate of occurrence of

FIG. 1.



Frequency of occurrence of bursts of ionization at sea level as a function of the thickness of lead producing them. Lower curve: bursts greater than ten rays, from data of R. T. Young. Upper curve: bursts greater than 10^6 ion pairs, authors' data.

bursts of ionization greater than 10^5 ion pairs was measured as a function of the amount lead shot in the container. These bursts were produced by approximately the same numbers of rays as in Young's observations. The results are illustrated in Fig. 1, which shows also R. T. Young's data. No attempt was made to attain great accuracy, and only a sufficient number of bursts were recorded to get the rough shape of the curve. It is seen that the agreement of the two sets of data is good. We conclude that the large number of bursts occurring at large thicknesses does not depend upon the presence of the side shields, but that these bursts actually emerge from the thick covering layer.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

GROWING OPTICALLY CLEAR SODIUM NITRATE CRYSTALS.

The problem of a supply of a doubly refracting material suitable for the construction of polarizing prisms and other related optical parts is an acute one. Calcite has become scarce and material suitable for large polarizing prisms is almost impossible to obtain. As far back as 1921, a study of this problem was begun at the Bureau. Crystallization studies were undertaken to find some method of producing a substitute for calcite. Sodium nitrate belongs to the same crystallographic system as calcite and is even more strongly doubly refracting. If large clear crystals of this material could be produced of suitable size and perfection for optical use, not only would the common diffculties associated with the present scarcity of calcite be eliminated, but the production of polarizing prisms with an aperture of 10 mm. or larger would become possible. Moreover, sodium nitrate, due to its much larger double refraction, would have certain advantages over calcite. It has the minor disadvantages, however, of being rather soft, easily cleaved, and soluble in water.

The Bureau's first experiment in growing sodium nitrate crystals (undertaken in 1921) had to do with the deposition of the crystal from water solution. As a result of this experiment, it was found necessary to grow the crystal very slowly if striæ and inclusions were to be avoided. It required several months to grow crystals only about 2 cm. on each edge.

More recently, F. B. Phelps and Frederick Bates have grown optical material from the melt. They have found that the crystals grow rapidly in comparison with their development from water solution, larger and clearer crystals being obtained in a few hours than were obtained in weeks from water solution. In fact, an overnight crystallization fre-

* Communicated by the Director.

quently produces perfectly formed crystals as large or larger than any of the calcite crystals that have been on the market in many years.

Although the apparatus thus far utilized was not designed for the work, satisfactory optical material has been produced, in spite of the fact that the furnace is not of the proper dimensions to give the very small temperature gradient desired. Single crystals have been obtained with the same diameter as that of the container, about 13.5 cm., and about 5 cm. in height. In practically every case after the crystal has grown evenly to a thickness of about 2 inches it begins to grow faster up the sides of the container than in the center, forming a deep bowl-like depression. Crystallization then proceeds from the walls in toward the center, resulting in the formation of a number of crystals with distinct boundary lines. This effect is probably produced by the gradient characteristics of the furnace and would disappear if a properly designed furnace were used. The largest crystal so far obtained weighs about 2.5 kilograms (5 pounds).

PROGRESS REPORT ON INDUSTRIAL USES OF SILVER.

Since the item in Technical News Bulletin 249 (January, 1938), outlined the general plan of the American Silver Producers' Research Project, the present report will be confined to the status of the project as summarized by the research fellows in their Fifth Progress Report submitted to the sponsors on March 1. It is to be understood that the following observations are based only on this report and are merely tentative, since the work is still in progress and has not been completed in any instance.

Biological Action of Silver Salts.—Physicochemical tests are being conducted to determine, if possible, the mechanism of the reaction between silver salts and proteins, especially those derived from bacteria.

In connection with the toxicological studies, some 600 references have been collected and the records of 240 cases of argyria (silver poisoning) reviewed. This research has shown that, while the indiscriminate and uncontrolled use of silver compounds in humans is wrong and can lead to the develop-

ment of argyria, it may be tentatively concluded that the reasonable use of silver medically is justified and apparently safe, that it causes no impairment of the general health, that there is no marked individual susceptibility, and that it is probable that the safe dose of silver is the equivalent of about 6 grams of the nitrate administered over a long period of time. The physiologic equivalents of other salts have not yet been determined.

Dr. Donald M. Pillsbury and Dr. W. R. Hill, also at the University of Pennsylvania medical school, are making a study of argyria (silver poisoning). Although Dr. Hill has discovered no instance of argyria in animals in the course of his very complete search through the medical literature, an effort is being made to bring about systemic silver poisoning in white rabbits, and thus obtain much-needed data on this subject. They point out that the indiscriminate and uncontrolled use of silver compounds in humans will lead to the development of argyria in some cases, but conclude that the reasonable use of silver medically is justified and apparently safe.

The lethal effect of silver on fungous organisms has been demonstrated by L. W. Nielsen, Cornell research fellow under direction of Dr. L. M. Massey, head of the department of plant pathology. One part of silver per million is toxic to organisms in fish hatchery water. The exact silver ion concentration low enough to be harmless to plants or fish yet high enough to be toxic to the organisms that attack plants and cause high mortality in fish hatcheries, remains to be determined. The possibility of using a silver spray solution in viticulture is considered most promising.

Catalytic Properties of Silver.—Dr. A. R. Day and T. Immediata of the department of chemistry, University of Pennsylvania, have studied the efficacy of silver as a catalyst in the oxidation of ethyl alcohol to acetaldehyde and acetic acid. The use of samarium-promoted silver in a silver tube, under regulated conditions of operation, was found to give higher conversions and higher total yields than have been reported in the literature. The promoter lowers the required temperature, and the silver tube prevents localized hot-spots, thereby minimizing undesirable side-reactions.

Heat Transfer Properties of Silver.—In coöperation with Dr. N. W. Krase of the department of chemical engineering, University of Pennsylvania, S. J. Wilkins has designed an improved apparatus for the study of vapor condensation and heat transfer. Preliminary data have been obtained with acetone and ethyl alcohol vapors condensing on a silver tube, and drop-wise condensation (as compared to film-type) of these organic vapors has been observed, possibly for the first time.

Physico-chemical Properties of Silver and Silver Salts.—The properties and utilization of silver compounds, the welding of silver to silver at low temperatures, and the diffusion and absorption of oxygen in silver are under investigation at Lehigh University by G. R. Van Duzee under supervision of Prof. Allison Butts. Calculations based on data in the technical literature have indicated that silver, being permeable with respect to oxygen but not with respect to nitrogen at elevated temperature, could be utilized to fractionate air. The practicability of using this peculiar property to enrich air for blast furnace use is being studied. Similarly, consideration is being given to the use of an oxygen-absorption cycle, taking advantage of the high solubility of oxygen in molten silver and the change of solubility with both pressure and temperature. Other experiments are in progress to determine the conditions of pressure, temperature, and time involved in the "cold-welding" of silver to silver, occasionally encountered industrially. The properties of the sulphide and other salts have been studied, but as yet only to a limited extent.

Electrodeposition of Silver and Silver Alloys.—This phase of the project is being investigated by L. I. Gilbertson and Aaron Johnson, research fellows under guidance of Dr. F. C. Mathers at Indiana University.

A procedure has been worked out for the production of thick (.01–.05 in.) adherent deposits of silver on steel. In addition to a direct deposition method, details have been worked out for a process utilizing an intermediate electroplate of a third metal, particularly copper. The relationship between thickness of deposits and imperviousness of the electroplate is being studied.

Nickel, cobalt, cadmium, copper, iron, zinc, and lead have been co-deposited with silver from aqueous solutions, resulting in deposits possessing interesting properties, for instance: Silver-nickel alloys are notably hard; silver-iron alloys, while not tarnish-proof, are notably corrosion-resistant; the highest resistance to sulfide tarnish was noted in a deposit plated out of silver beryllium nitrate tartrate solution, this deposit giving qualitative test for beryllium.

Since silver deposits can readily be stripped from aluminum cathodes, the latter might serve as starting sheets for the production of films and sheets of silver.

An extensive and annotated bibliography on silver plating has been compiled.

Electrical Properties of Silver.—At Rensselaer Polytechnic Institute, Prof. S. B. Wiltse and D. P. Miles have been studying the characteristics of sliding silver contacts and silver-graphite brush materials. Substantial decrease in power losses, and better slip ring and commutator contacts are indicated. The best results have been obtained with high silver content silver-graphite brushes, which seem, incidentally, to confer on copper rings the properties of a silver ring by virtue of the film of silver transferred to the copper. Automobile starter motor tests are in progress, and the mere substitution of silver-graphite for copper-graphite brushes indicates a gain of 20 per cent. for the same input. Even more favorable is the comparison between commutation of the silver-silver contact and the carbon-copper contact. Some advantages indicated are: Lower contact drop; linear current-voltage relation; absence of appreciable polarity effect; and ability to operate at higher current densities. New opportunities for improved design of electrical equipment appear to exist.

Aviation Engine Bearings.—At the time the Silver Research Project was being organized, the use of substantially pure silver as a bearing metal for aviation engine use was passing from the laboratory to the production stage, and it was decided to establish a fellowship at Batelle Memorial Institute to obtain information on the possibilities and limitations of silver bearings. Dr. R. W. Dayton, a member of the Institute's staff, was appointed research fellow. His

studies have shown that alloying silver with another metal results in inferior antifrictional qualities; the best results are obtained with the purest silver. Of a large number of alloying elements studied, only sulphur seemed to produce any improvement, while lead and copper in small amounts were slightly inferior to pure silver. High thermal conductivity, absence of galling and scoring, and high strength are favorable features of the silver bearing. Some unusual surface properties are probably also involved, as indicated by recent tests showing the insensitivity of silver to old and new lubricating oil, unlike copper-lead bearings which are sensitive to these variations. Tests conducted in a General Motors test machine showed that silver has unusually high load-carrying ability, even with bearings which are very narrow in proportion to their diameters.

Metallurgical Studies.—The metallurgical work, because of its extent, has been distributed among several research fellows. Corrosion resistance is being investigated at Columbia University by Dr. V. S. De Marchi under supervision of Dr. Colin G. Fink; response to heat-treatment by B. S. Old, under supervision of Dr. John T. Norton of the metallurgy department, Massachusetts Institute of Technology; and the preparation of alloys is in the hands of the research associates (A. J. Dornblatt, A. M. Setapen, and T. W. Allen) working in the Bureau's metallurgical division, supervised by H. S. Rawdon.

Approximately two hundred alloys are under investigation, and while definitive appraisal cannot be made at this time, certain trends have been noted, indicating that silver is a surprisingly effective alloy hardener of the solution-forming type.

Annealing studies at the Bureau have shown a general tendency of silver in amount of one to five per cent. to raise definitely the annealing temperature of wrought brass, bronze, aluminum bronze, and manganese-silicon bronze.

In addition, Mr. Old has shown that interesting aging properties are developed in certain alloys of the following types: Cu-Sn-Ag, Cu-Zn-Ag, Cu-Al-Ag, Ag-Al, Ag-Al-Ti, Cu-Be-Ag, Cu-Ni-Ag, Al-Mg-Ag, Cu-Si-Mn-Ag, Al-Si-Ag, Mg-Zn-Ag, Ag-Cu-Si, Ag-Si, Mg-Sn-Ag. The most promising

improvement produced by silver and heat-treatment is noted in the tin bronzes, the beryllium bronze where silver replaces some of the beryllium, and the light magnesium-tin alloys. Contrary to expectations, the silver-silicon alloys, rich in silver, are notable for their response to heat-treatment. A very thorough study is being made of the magnesium-tin alloys with 2½ per cent. of silver.

It is believed that the slight solubility of silicon in silver, combined with precipitation hardening properties of alloys containing less than eutectic silicon content, offer a type of alloy that can be used in the chemical and electrical industries to advantage, because of its corrosion resistance, hardness, strength, and relatively high conductivity, both thermal and electrical. Later studies will determine the practicability of adding other elements to improve the general hardness of this type of alloy.

It seems possible that improved materials for gears can be made from the heat-treatable ten per cent. tin bronze containing silver.

Corrosion tests have shown that (with the exception of certain aluminum and magnesium-base alloys) the addition of up to one per cent. of silver has little if any harmful effect, although generally higher silver up to 5 per cent. may moderately accelerate corrosion in a brine solution. This seems to apply to brass, bronze, aluminum bronze, beryllium bronze, and cupro-nickels. Up to about 15 per cent. silver additions reduce the corrosion of zinc.

Dr. De Marchi has produced some very interesting specimens of silver-iron "alloys from metal powders, sintered, and worked to sheet. He is also studying a silver storage battery characterized by its ability to take high charge and discharge rates. A ten per cent. potassium chromate electrolyte has been found advantageous.

Miscellaneous Activities.—The senior research associate at the Bureau, A. J. Dornblatt, has personally visited more than one hundred industrial and research organizations to acquaint them with the project and exchange data relating to silver.

A list of metallurgical patents relating to silver alloys and to sterilization by silver has been prepared, as well as a list

of chemicals and the suitability of silver to withstand their attack.

Through coöperation with an industrial manufacturer of cans, a relatively inexpensive form of solderless silver-lined container suitable for shipment and storage of food-stuffs, pharmaceuticals, and chemicals has been developed. Twelve-ounce containers have been produced from silver-clad copper and steel sheets, .012 inch thick, with the silver cladding .001 inch in thickness, and the development of larger sizes is now in progress.

Since all of the research work being done on the project is "open" and none of it is subject to patent, information on any details of the Silver Research Project can be obtained by writing Mr. Dornblatt at the National Bureau of Standards, Washington, D. C.

PLASTICS AS STRUCTURAL MATERIALS FOR AIRCRAFT.

Plastics and aircraft have undergone their major development during the past twenty years. Both are industries in which many optimistic predictions for a generation of progress have become realities within two to five years. Currently, efforts are underway in England and Germany to link more closely these two relatively new and expanding industries by utilizing plastic materials for the construction of aircraft. Admittedly this is a development the realization of which would appear to require many years of experimental research on materials and fabrication problems. However, noteworthy progress has already been made by Kraemer in Germany, and de Bruyne, de Havilland, King, and Walker in England. The work of these and other investigators was summarized in a paper presented by G. M. Kline, chief of the organic plastics section of the Bureau, at the meeting of the Institute of the Aeronautical Sciences in New York on January 24, 1938.

Most of the experimental work on plastics in aircraft construction has been with reinforced phenolic resins, known in this country by such trade names as "Bakelite," "Durez," and "Durite." In the usual molding composition the resins are mixed with wood flour. Plastics of greater mechanical

strength are produced by employing paper or cloth as the reinforcing medium. Phenolic laminated materials of this type have already found many applications in the aircraft, automotive, railroad, telephone, power, and building industries. Kraemer found that products superior to the paper—or cloth—laminated type in certain physical properties, especially modulus of elasticity in both tension and compression, could be prepared by impregnating thin strips of wood (0.004 to 0.012 in. thick) with resin and forming them into a multilayered cured sheet in the usual manner. De Bruyne has worked primarily with cord or long fiber reinforcing agents in order to obtain maximum tensile strength, incorporating only the minimum amount of resin required to bind these fibers together.

Physical properties of these various types of plastics which are pertinent to their use as structural materials for aircraft were discussed, including density, tensile, compressive, flexural, shear and torsional strengths, moduli of elasticity, endurance limit, impact strength, energy absorption, and corrosion resistance. Similar data from the literature were cited for materials which have been commonly employed for fabricating aircraft, namely, high tensile steels, aluminum and magnesium alloys, aircraft spruce, and birch plywood.

The exploration of the potential applications of reinforced plastics to aircraft construction must include problems relating to: The choice of resin and reinforcing material; the method of combining and forming them into a suitable product; the testing of such products to determine whether they possess the requisite physical characteristics; the design of structural members to take full advantage of the properties and fabrication possibilities of plastics; and the equipment for forming the separate sections, and the technique of joining these sections to produce the finished aircraft. It has been suggested that progress in the utilization of plastics in aircraft construction will be made by the gradual introduction of these materials into an otherwise orthodox structure, and that the early stages of this development will involve the molding of such small units as fins and rudders and the fabrication of the larger units from reinforced sheets and molded sections by conventional methods of jointing. However, until more information is available on

the problem of combining resin and reinforcing agent in such manner as to obtain requisite strength and stiffness, and until such products have been thoroughly tested to determine their behavior under repeated stresses, it is too early to expect any considerable progress on the design and fabricating problems.

ACCURACY OF RADIO METEOROGRAPH OBSERVATIONS.

The radio meteorograph balloon system which the Bureau has devised for the U. S. Navy Department was described in Technical News Bulletin 250 (February, 1938).

In several recent comparisons between radio meteorograph and aerograph observations, it was noted that the trends of temperature variations as indicated by the two instruments were quite dissimilar. Careful analysis led to the conclusion that the differences were actually caused by the geographic separation of the two instruments in the air mass and not by errors in their indication. Such effects were noted during an unstable air mass or when strong winds carried the balloon away to a considerable distance from the airplane.

To check this hypothesis, a series of six simultaneous radio meteorograph, aerograph, and ordinary meteorograph soundings were made. In each test, the meteorograph (a recording instrument, recovery of which is required to evaluate the record) was attached to the same balloon as the radio meteorograph. Four of the meteorographs were recovered and three gave complete records. In each case, the meteorograph observations agreed faithfully with the radio meteorograph readings, and both balloon instruments showed the same differences in trend from the aerograph observations. This proves conclusively that there are differences in the character of portions of even a stable air mass, provided they are separated by an appreciable distance.

On the basis of the results of 50 radio meteorograph and aerograph comparisons and of the 3 radio meteorograph, aerograph, and ordinary meteorograph comparisons, an estimate of the absolute accuracy of the radio meteorograph can be made. It provides pressure measurements accurate to $\pm$ 2 millibars (1½ millimeters of mercury), temperature

readings accurate to ± 1° C., and humidity readings accurate to ± 5 to 8 per cent. relative humidity.

REFRACTIVE INDEX AND DISPERSION OF DISTILLED WATER.

In order to permit the accurate use of distilled water as a standard sample in precision refractometry, Leroy W. Tilton and John K. Taylor have made determinations of the refractive index and dispersion of distilled water for visible radiation, at temperatures from 0 to 60° C. A spectrometer, water-jacketed hollow prisms of nickel, and platinum-resistance thermometers were used in the minimum-deviation measurements. Samples from a continuously operating still were taken on 93 days during a period of 3 years and observations at 133 temperature-wave-length coördinates were repeated on each of three days by each of the authors. All known requisites for precision and accuracy within approximately $\pm 1 \times 10^{-6}$ in index were employed, and the results, which are given in the April number of the *Journal of Research* (RP1085), are corrected so as to refer to dry air at a pressure of 760 mm. and at the temperature of the water.

The data were adjusted by least squares, and are represented by a general formula having 13 constants, the average of the 133 residuals being 1.2×10^{-6}. A general double-entry table of refractive indices (6,776 listed values) with temperature and wave-length as arguments has been computed to yield sixth-decimal-place data by linear interpolation. More specific tables give indices for the D lines of sodium and for 12 other commonly used spectral lines. The maximum refractivity of water is found to be near 0° C., but the exact temperature is a function of the wave-length, with a total variation of approximately 0.5° C. for the visible spectral range. Tables and graphs for specific refraction and for partial dispersions are given, and evidences of slight systematic errors are discussed.

The precision of these data is higher than has hitherto been attained but there is marked disagreement (approx. $\pm 1 \times 10^{-4}$) with some of Flatow's indices which have been widely used and are the basis for the data on water as given in the International Critical Tables. The authors' opinions

concerning the accuracy of their results are qualitatively confirmed by the medial relation of their data to all of those previously published, and quantitatively, within the temperature range 0 to 16° C., there is remarkably close agreement with the interferometrically determined indices of water as reported by Mlle. O. Jasse.

LIVELINESS OF BASEBALLS.

At the request of Clark Griffith, president of the Washington Baseball Club, and because of the considerable public interest in the matter, the Bureau recently conducted a series of tests to determine whether or not there is any difference in the liveliness of the ball used by the American League as compared with the ball used by the National League.

The "liveliness" or resilience of a body is commonly determined by allowing it to fall and rebound from a suitable hard surface. A lively ball rebounds more than a dead ball. However, this method is not satisfactory for baseballs. The principal reason is that the velocity with which the ball leaves the bat in a home run hit is far greater than can be obtained by dropping the ball from any reasonable height. The impact of a ball dropped from the top of the Washington Monument or higher on to the pavement below is probably not as great as that of the bat hitting a fast ball. The falling ball is retarded by the resistance of the air and soon approaches a constant speed at which the air resistance equals the weight. This speed has not been accurately determined, but is probably of the order of 120 ft./sec. The relative speed at which the bat meets a fast ball is probably greater. In any case large corrections would have to be made for the effects of air resistance in the measurement of liveliness by dropping tests.

As it was necessary to secure impacts comparable with those of a batted ball (because liveliness decreases and deformation of the ball increases in proportion to severity of impact), a machine was constructed at the Bureau which gives relative speeds of the right order of magnitude. The machine, which is an adaptation of one developed by Prof. H. A. Thomas of the Carnegie Institute of Technology for

measuring the liveliness of golf balls, consists of an air gun shooting a one-pound hard-wood projectile (representing the bat) at speeds up to 200 ft./sec. against the ball. After impact, the projectile and ball are caught in ballistic pendulums, by means of which their speeds can be determined. The resilience or "liveliness" is measured by the ratio of the relative speeds after and before impact.

As a result of the Bureau's tests, it has been shown that there is no difference of any practical significance between the balls used by the two leagues. Some National League balls are more lively than some American League balls, and some are less lively. There are slight variations in liveliness of balls of either league, just as there are slight variations in weight within the official limits of 5 to 5¼ ounces and slight variations in circumference within the official limits of 9 to 9¼ inches. The differences between averages of three measurements on six balls of each type are small in comparison with variations in the individual measurements and would probably disappear if a very large number of balls were tested.

As a check on the laboratory results, the testing machine was taken to the Washington ball park and used as a robot batter to drive out home runs. It was easily possible to knock the ball over the fence. Numerous measurements of distance were made under the same conditions, in so far as possible. The average distance was the same for the American and National League balls within one foot, namely 367 feet for the conditions used. Individual shots went from 320 to 410 feet, this scatter and lateral deflections up to 30 feet either way being largely due to the effect of the variable wind.

Precision in Manufacture Improves Lamp Quality.—E. W. BEGGS. (*Electric Journal*, Vol. 35, No. 2.) The materials of which an electric lamp is made, the design, and the precision with which this design is executed have a great effect on the value of a lamp to the user. As a matter of fact, while invention has contributed enormously to the continuous rise in output in light of a lamp, a still more important role in lamp history is attributable to care and plain old fashioned "tending to business" in the factory. Lamp makers have so refined and controlled their processes that they can put into a lamp what characteristics they please. In the making of a filament the ore, Wolframite, is processed to give tungsten as a pure oxide—a yellow powder. Changing this powder to a fine wire is a modern manufacturing miracle; it is "doped" and heated and tested and pressed and brought to a white heat in a hydrogen furnace. When it finally emerges as an ingot, it must be drawn into the extremely fine wires—smaller than human hairs—through diamond dies, which themselves are results of great precision. Just as important is the winding of the wire into coiled or recoiled filament, assembling in the glass bulb, exhausting the bulb, mounting the base, and connecting the lead wires. The effect of overlooking the slightest detail is amazing. In evacuating the bulbs, for instance, the vacuum must be practically perfect, with no moisture whatever left inside. One drop of water distributed equally in 100,000 lamps is enough to destroy the performance of those lamps.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, APRIL 20, 1938.

The regular monthly meeting of The Franklin Institute was called to order at 8:30 o'clock by Mr. Philip C. Staples, President of the Institute. The minutes of the previous meeting were approved as printed in the April issue of the JOURNAL.

The Board of Managers recommended the election of the following gentlemen to Honorary Membership in the Institute, because of their participation in the Dedication Ceremonies on May 19, 20 and 21:

Dr. George D. Birkhoff	Dr. Louis Martin
Dr. Harvey N. Davis	Dr. C. E. K. Mees
Dr. Arthur L. Day	Dr. T. H. Morgan
Dr. Merritt L. Fernald	Dr. Forest R. Moulton
Sir James C. Irvine	Dr. W. E. Wickenden
Dr. Gilbert N. Lewis	Dr. Abel Wolman

The recommendation was unanimously approved.

The Secretary then presented a statement of the additions to membership since the last report as follows:

Honorary members	12
Active members	7
Associate members	12
Student members	23
Total	54

He also announced that because of the Dedication Ceremonies the May meeting of the Institute will be held on Friday evening, May 20, instead of Wednesday evening, May 18.

The Chairman then introduced Dr. W. F. G. Swann, Director of the Bartol Research Foundation, who presented his Annual Report of the Activities of the Laboratory. He reported on some of the most important investigations in progress during the year 1937 and 1938, and described especially the extensive research in cosmic-rays and nuclear physics. Accounts were given of the phenomena concerned with cosmic-ray showers, variation of cosmic-ray intensity with altitude, and theories of cosmic-ray phenomena. He also referred to the experiments on neutrons, and experiments on the generation of electron pairs. Special developments in experimental devices were described including those having relation to the cyclotron.

The subject was illustrated by numerous experiments and lantern slides.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, April 13, 1938.)

HALL OF THE COMMITTEE,
PHILADELPHIA, APRIL 13, 1938.

MR. EDWARD L. FORSTALL *in the Chair.*

The following report was presented for final action:

No. 3055: Henderson Medal.

This report recommended the award of the George R. Henderson Medal to Clyde C. Farmer, of Pittsburgh, Pennsylvania, "In consideration of his invention and development of the 'AB' Freight Brake which has, in large measure, solved the difficulties and intricacies of a complicated problem in Railway Engineering." Special commendation of his associates for their assistance in its development was also recommended.

JOHN FRAZER,
Secretary to the Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is thirty-five cents.

The library and reading room are open Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 784 readers made use of the facilities during the twenty-seven days of March.

RECENT ADDITIONS.

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Royal Agricultural Society of England. Journal Volume 98. 1937.

Aviation.

LANGLEY, M. Metal Aircraft Construction. Third and Revised Edition. 1937.

Bibliography.

HARDWICKE, ROBERT E. Petroleum and Natural Gas Bibliography. 1937.

Biography.

Chemical Who's Who. Volume 2. 1937.

CURIE, EVE. Madame Curie. A Biography . . . Translated by Vincent Sheean. 1938.

Chemistry and Chemical Technology.

American Gas Association. Proceedings. Nineteenth Annual Convention. 1937.

HEILBRON, I. M., AND OTHERS. Dictionary of Organic Compounds. Volume 3. 1938.

HESSENLAND, MAX. Praktikum der gewerblichen Chemie. 1938.

KREPS, THEODORE J. The Economics of the Sulfuric Acid Industry. 1938.

LOCKREY, A. J. "Plastics" in the School and Home Workshop. 1937.

MCDONOUGH, EVERETT G. Truth about Cosmetics. 1937.

NORD, F. F., AND R. WEIDENHAGEN. Ergebnisse der Enzymforschung. 7 Band. 1938.

Dictionaries.

Van Nostrand's Scientific Encyclopedia. 1938.

Electricity and Electrical Engineering.

HARLOW, ALVIN E. Old Wires and New Waves. The History of the Telegraph, Telephone, and Wireless. 1936.

MAIER, KARL. Trockengleichrichter: Theorie, Aufbau und Anwendung. 1938.

ROTH, ARNOLD. Hochspannungstechnik. Zweite vollständig neubearbeitete und vermehrte Auflage. Herausgegeben unter Mitwirkung von Professor Alfred Imhof. 1938.

WILSON, J. C. Television Engineering. 1937.

Engineering.

SALMON, E. H. Materials and Structures. A Text-Book for Engineering Students. Volume 2: The Theory and Design of Structures. 1938.

SCHOKLITSCH, ARMIN. Hydraulic Structures. A Text and Handbook. Translated by Samuel Shulits. Translation Reviewed by Lorenz G. Straub. Volumes 1–2. 1937.

SHERLOCK, R. H., AND OTHERS. Storm Loading and Strength of Wood Pole Lines and a Study of Wind Gusts. 1936.

Verein Deutscher Ingenieure. Technik Geschichte. Beiträge zur Geschichte der Technik und Industrie. Band 26. 1937.

Geology.

BEYSCHLAG, F., P. KRUSCH, AND J. H. L. VOGT. Die Lagerstätten der nutzbaren Mineralien und Gesteine nach Form, Inhalt und Entstehung. 3. Band: Kohle, Salz, Erdöl, herausgegeben von Prof. Dr. P. Krusch; 2. Teil: Steinsalz und Kalisalze von Dr. Ernst Fulda, mit einem Beitrag über die Salzlagerstätten Russlands von Dr. N. Polutoff. 1938.

Hygiene and Physiology.

New York Academy of Medicine. Milestones in Medicine. Laity Lectures of the New York Academy of Medicine. 1938.

Manufactures.

American Foundrymen's Association. Transactions. Volume 45. 1937.

BRITTEN, F. J. Watch & Clock Makers' Handbook Dictionary and Guide. Fourteenth Edition, Revised by J. W. Player. 1938.

Naval Architecture and Navigation.

DUTTON, BENJAMIN. Navigation and Nautical Astronomy. Fifth Edition. 1934.

RODGERS, WILLIAM LEDYARD. Greek and Roman Naval Warfare. A Study of Strategy, Tactics, and Ship Design from Salamis (480 B.C.) to Actium (31 B.C.). 1937.

Patents.

THOMAS, EDWARD. The Law of Chemical Patents. Second Edition, Revised and Enlarged. 1938.

U. S. Patent Office. Index of Patents Issued 1937. 1938.

U. S. Patent Office. Index of Trade Marks Issued 1937. 1938.

Pharmacy.

ERB, RUSSELL C. Poisoning the Public. Daily Contacts with Toxic Materials as Civilization Marches On. 1937.

GLASER, HUGO. Poison. The History, Constitution, Uses and Abuses of Poisonous Substances. Translated into English by Marguerite Wolff. 1937.

Physics.

BRIDGMAN, P. W. The Nature of Physical Theory. 1936.

CLARK, C. H. DOUGLAS. The Fine Structure of Matter. The Bearing of Recent Work on Crystal Structure, Polarization and Line Spectra. Being Volume 2 of A Comprehensive Treatise of Atomic and Molecular Structure. Part 1: X-Rays and the Structure of Matter. 1937.

GREEN, S. L. Hydro- and Aero-Dynamics. A Theoretical Textbook for Advanced Students of Aeronautics, Hydraulics, Physics and Mathematics. 1937.

RUHEMANN, M., AND B. RUHEMANN. Low Temperature Physics. 1937.

Scientific Essays.

British Association for the Advancement of Science. Report of the Annual Meetings. 1932–1937. Six volumes.

Royal Society of London. Philosophical Transactions. Series A, Volume 236. 1937.

BOOK REVIEWS.

MILESTONES IN MEDICINE, LAITY LECTURES OF THE NEW YORK ACADEMY OF MEDICINE, Introduction by James Alexander Miller. 275 pages, illustrations, 13 × 20 cms. New York, D. Appleton-Century Company, 1938. Price $2.00.

This book consists of a series of lectures of the New York Academy of Medicine during 1936–37 by men outstanding in their fields. The aim of the work is not only to make it possible for the non-professional to become acquainted with facts, but to give understanding of them. The difference between a knowledge or acquaintance and an understanding or appreciation is very ably brought

out by James Alexander Miller, M.D., in the introduction to the work. He states, "For example, it is common knowledge that the rhythmic contractions of the heart produce electrical currents and that these currents may be registered by means of an electrical apparatus known as electrocardiograph. It is thus possible to diagnose certain changes in heart structure and function by a study of the electrical currents produced by the heart. This is called electrodiagnosis. Many, knowing of this feat of modern medicine, precisely because of this knowledge, have fallen victims to unscrupulous quacks, who pretend that they can electrodiagnose all diseases to which the human flesh is heir, from anemia to zoster."

This gives a very good illustration of the intent of the lectures—to give understanding and ability to appreciate. There are eight lectures by as many contributors. They include, The Historical Background of Psychiatry, The Mechanisms of Heredity, Medicine at Sea in the Days of Sail, The Evolution of the Human Brain, The History of Medical History, The History of Leprosy, and The Story of the Glands of Internal Secretion. Each of these is a story in itself, instructive, easy to read, and should add much to the culture of the non-professional reader.

R. H. OPPERMANN.

COLLOID SYSTEMS, A SURVEY OF THE PHENOMENA OF MODERN COLLOID PHYSICS AND CHEMISTRY, by Priv.-Doz. Dr. A. Von Buzagh, translated by Otto. B. Darbishire. 311 pages, illustrations, tables, 16 × 25 cms. London, The Technical Press Ltd., 1937. Price $9.00.

Colloid science occupies a unique position in the world of sciences. In the history of the sciences, for years it was either ignored or it was referred to as a state where there was a true solution or a mechanical suspension. Early in the present century with the introduction of the conception of the dispersed condition of matter, came the recognition of the colloidal state. From this time progress was increasingly apparent until today colloid science is recognized as something very definite which has justified its existence through confirmation of experiments, and where the classical laws of physical chemistry cannot be directly applied. While it is a separate science it is not to be regarded as completely isolated from pure chemistry and physics but rather an extended chapter of physical chemistry, very rich in specialized laws.

This is the view of the author of this book upon which his work is based. In this work there is given an objective account of the leading principles of the science and attention is drawn to the close relationships between physical chemistry and the study of colloids. It begins with discussions bringing out the understanding of colloidal discontinuities and what systems are to be regarded as colloidal systems. To this general definition there is added a stereometric definition which is substantiated through a determination of the functions of dispersion and difformation, representing the variations of physical and chemical properties in relation to the degree of dispersion and difformation. Following this the reader is led through a discussion on the morphology of difform and disperse systems and then to the obtaining of an insight from the atomic viewpoint, an opposite method from that preceding. Here the subject is treated as aggregates, which are structures consisting of individually complete and dynamically

interdependent building units. Between these units certain combining forces act which give the whole structure an internal cohesion and an external completeness. First primary aggregates are taken up, or those formed by the so-called primary combining forces. Then secondary aggregates are covered which are built up from primary aggregates by secondary combining forces.

A very interesting part of the book is that devoted to interfacial phenomena wherein there are treated the subjects of adsorption and the electrical properties of disperse systems. This is followed by the change of state of colloids, the formation, destruction of the solution, and the internal change of state where spontaneous changes are the changes in degree of dispersion and spatial distribution in the system when undisturbed without the application of external energy and forced changes are those which occur upon the application of external energy.

Finally there is discussed an important controversial question. Are colloids undefinable and non-reproducible systems? Is there thought precision in the colloidal science? Are there erroneous conclusions?

The book should go far in providing the mental reorientation necessary for the satisfactory comprehension of colloid science.

R. H. OPPERMANN.

THE FINE STRUCTURE OF MATTER, THE BEARING OF RECENT WORK ON CRYSTAL STRUCTURE, POLARIZATION AND LINE SPECTRA, being Volume II of a comprehensive treatise of atomic and molecular structure. Part I: X-Rays and the Structure of Matter, by C. H. Douglas Clark. 216 pages, illustrations, tables, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1937. Price $4.25.

Much has been written and said recently with regard to thought and development, of the new atomic and molecular theory. Progress in the past ten to fifteen years has been marked, so that today there is need for up-to-dateness in conception in many diverse fields of endeavor. The Fine Structure of Matter is a book which belongs to a series. It is Part I of the second volume of a comprehensive treatise on atomic and molecular structure and is devoted exclusively to X-rays and the structure of matter. The intent of the series is to acquaint research workers in specialized branches with developments not in the immediate sphere of thought and to correlate the work in different lines which has been carried on more or less independently.

The book at hand is of the nature of a review of the situation of the work of many outstanding leaders of the subject. Reference is made in the Preface to the statement of V. K. La Mer in Chemical Reviews, 1929, in which he recognized the X-ray, the dielectric cell, and the spectroscope as the three instruments of special significance in the search for more knowledge of nature. The X-ray is the subject of this book and its coverage is of crystal and related structures as determined by X-rays. It is divided into nine chapters of from 15 to 30 pages each, beginning with discussions on space-lattices and proceeding through chapters on crystal structures and the classification of various types, both organic and inorganic. The same thing with regard to colloids, amorphous substances, alloys, intermetallic compounds and solid solutions is also well covered later. The concluding chapter is on crystal structure and molecular constitution wherein the main subject is the taking into account of the general property relations

existing between crystals as a method of classification, differentiating from the previous work in the book as a method of classification from the standpoint of the X-ray crystallographer, into space groups and types of cells. It is pointed out here that although a close relation exists between structure and behavior, the two methods of classification may not always lead to the same results.

The book, by its very nature, requires the recording of a large number of references which is done in a very complete and efficient manner. Likewise the illustrations, which are an indispensable part of the work, are well done. A name and subject index are appended.

The author is to be congratulated in presenting here a summary devoted to an interesting, although highly technical, subject in a manner that is not too difficult for understanding.

R. H. OPPERMANN.

NATIONAL FIRE PROTECTION ASSOCIATION. The National Fire Codes for Flammable Liquids and Gases, compiled by Robert S. Moulton. Boston, Association, 1938. Price $1.50.

The National Fire Protection Association in the course of its work has prepared a great number of standards in various forms on the subject of safe-guarding life and property against fires. These standards are used to a very great extent by a wide scope of people so that the National Fire Protection Association has become very well known, although the standards are only one of the activities of the association. The present volume is a compilation of the standards dealing with the various phases of the regulation of the hazards of flammable liquids and gases. There are some thirty-five contained herein in the form of suggested ordinances, regulations or recommended good practice requirements. The field covered includes; the storage of flammable liquids in rooms, cabinets and outside houses; marine oil terminals; tank trucks; oil burners; gasoline stoves, torches and vapor lamps; liquefied petroleum gas systems, trucks, and as motor fuels; internal combustion systems; motor craft; air craft fueling operations; city gas; anaesthetic gases; etc. Following all this there is quite an extensive tabulation on the fire hazard properties of a large number of flammable liquids, gases, and volatile solids. This data has been compiled from some forty-three reference sources and includes the flash point, ignition temperature, explosive limits in air, vapor density, and the Underwriters' Laboratories' Classification. The book should be a very handy addition to a set of work books.

R. H. OPPERMANN.

NATURE PHOTOGRAPHY AROUND THE YEAR, by Percy A. Morris. 251 pages, plates, 15 × 22 cms. New York, D. Appleton-Century Company, 1938. Price $4.00.

The amateur photographer is no rare specimen today. Everywhere in the United States, in crowded cities, in the country, at the seashore, he may be seen taking "shots" of buildings, individuals, landscape, in fact anything that strikes his fancy. America is picture conscious. Undoubtedly the greatest reason for this is the impetus given photography by the scientific developments of speedy lenses and supersensitive films of recent years. Today the amateur photographer is seldom prevented from obtaining a good print by bad weather

or any of the other obstacles of a few years ago. In science and industry photography has likewise proved very useful. Photographs are being made of substances in the process of change as well as of the heavenly bodies for practical use in observation and calculations.

The title of the book at hand implies a practical use of photography for the amateur. It suggests, that instead of taking pictures at random in a more or less indirect channel as to type, pictures be taken in the field of nature study with the result of having a collection that is permanent and not subject to decay or deterioration which would be the case were the specimens themselves collected. Whether the amateur be a photographer or a naturalist, the appeal is equal and as a matter of fact, the book provides ample inspiration and simple instruction for anyone to become a photographer-naturalist.

The author begins by setting forth the fundamentals necessary. From this point on, the economy of the hobby is placed as a background and there is very clearly brought to the reader's attention that a successful amateur does not need to spend fabulous sums. Photographic equipment needed is detailed, and methods for constructing suitable home made parts are described. Advice is given on cameras, films, plates, exposure meters, flashlight bulbs, as well as tripods and a carrying case for the equipment. Following this the months of the year are reviewed, what during these months make interesting photographs, how to take them including camera settings, etc., and the use of various accessories. A multitude of subjects are covered such as animals, birds, insects and flowers. Even landscapes during the different seasons are suggested. The book is well illustrated with a great many photographs and drawings of interest. At the end of the book there is a bibliography for further reference purposes. A subject index is appended.

The author's style of presentation is so simple and logical that readers of all classes will receive sufficient knowledge to persue a hobby just crammed full of pleasure, excitement, and adventure. The book can be placed with the existing few excellent works in this respect.

R. H. OPPERMANN.

AMERICAN WINGS, by Captain Burr Leyson. 214 pages, plates, 15 × 21 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $2.00.

Here is a book written in an easy-to-read style that should go far in popularity. It is a story of American aviation that has much value to those millions of citizens whose only knowledge of aircraft is from infrequent observation of the flight of a lone plane overhead. That aviation has a great future that will touch the lives of everyone is a factual conclusion, therefore it behooves Mr. Citizen to take notice and become acquainted with the up-to-dateness of aircraft and its innumerable services. He can be assured that the quest for knowledge in this direction will be thrilling as well as interesting.

American Wings is a book that everyone may find interesting. In the beginning the author paints a vivid picture of the part of aviation in modern warfare, the method of attack, and power of destruction. This is a reminder of the horrors of war and what is to be expected if we permit our defense forces to lag behind a point where they can cope with any attack upon us. Then the various types of army planes are examined and the purpose of their design

explained. The careful training of aviators is explained and the reader is given a ride in a fighting craft in which he experiences the numerous hair-raising tactics in the air such as the loop, spin, roll, etc.

Naval aviation is explained with its aircraft carriers, from the decks of which various types of planes are launched and landed. The types of planes and their duties and the rigid instruction of the naval aviator are all colorfully pictured. Turning from the military uses of aviation the author describes the services of the coast guard in the identification of vessels at sea, rendering of assistance, locating smugglers, and the transporting of sick people from aboard ship to shore. The commercial services of aviation are many and their importance is growing fast. There is described the American system of airways with which no other nation can compare, either in extent or in features. By means of the efficient radio range beacons maintained by the Bureau of Air Commerce an airman can fly from coast to coast, never see the ground and yet be unerringly on his course at all times. The efficiency of the mail service as well as the passenger transport lines is well known by hearsay. This book, however, gives first hand information on many details not so well known.

Transoceanic flying such as with the China Clipper is explained as well as the ships themselves. Skywriting, long distance and high altitude flying, flying for sport, the dirigible, and other subjects are all interestingly examined.

Mr. Average Citizen would do well to read this book and inform himself of the great achievements in this foremost activity of man.

R. H. OPPERMANN.

ONE HUNDRED YEARS OF TRANSATLANTIC STEAM NAVIGATION 1838–1938, by H. P. Spratt. 24 pages, plates, 25 × 15 cms. London, Science Museum. Price 6 d.

This is a small illustrated handbook prepared by Mr. H. P. Spratt who is responsible for the exhibition in the Science Museum, South Kensington, London, to commemorate one hundred years of transatlantic steam navigation. The purpose of the handbook is to set forth in very brief outline the history and development of the Atlantic Steam Ferry and at the same time to serve as a guidebook during the exhibition. It is divided into three parts; the paddle era, early screw steamers, and modern turbine ships. It makes interesting and instructive reading.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 617, Auto-Ignition and Combustion of Diesel Fuel in a Constant-Volume Bomb, by Robert F. Selden. 13 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

The variations in ignition lag and combustion associated with changes in air temperature and density have been studied for a Diesel fuel in a constant-volume bomb. The test results have been discussed in terms of engine performance wherever comparisons could be drawn. The highest test temperature approximated that attained in a compression-ignition engine in the usual range of injection advance angles. The test air densities ranged from something less than the compression density with normal aspiration to a value corresponding to considerable boost.

The most important conclusions drawn from this investigation are: The ignition lag was essentially independent of the injected fuel quantity. Extrapolation of the curves for the fuel used shows that the lag could not be greatly decreased by exceeding the compression temperatures and densities attained in modern high-speed compression-ignition engines. In order to obtain the best combustion and thermal efficiency, it was desirable to use the longest ignition lag consistent with a permissible rate of pressure rise.

Report No. 618, Comparative Flight and Full-Scale Wind-Tunnel Measurements of the Maximum Lift of an Airplane, by Abe Silverstein, S. Katzoff, and James A. Hootman. 7 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Determinations of the power-off maximum lift of a Fairchild 22 airplane were made in the N.A.C.A. full-scale wind tunnel and in flight. The results from the two types of test were in satisfactory agreement. It was found that, when the airplane was rotated positively in pitch through the angle of stall at rates of the order of 0.1° per second, the maximum lift coefficient was considerably higher than that obtained in the standard tests, in which the forces are measured with the angles of attack fixed. Scale effect on the maximum lift coefficient was also investigated.

Report No. 619, Drag of Cylinders of Simple Shapes, by W. F. Lindsey. 8 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

In order to determine the effect of shape, compressibility, and Reynolds Number on the drag and critical speed for simple forms, the drag forces on models of various simple geometric cross sections were measured in the N.A.C.A. 11-inch high-speed wind tunnel.

The models were circular, semitubular, elliptical, square, and triangular (isosceles) cylinders. They were tested over a speed range from 5 per cent of the speed of sound to a value in excess of the critical speed, corresponding, for each model, approximately to a tenfold Reynolds Number range, which extended from a minimum of 840 for the smallest model to a maximum of 310,000 for the largest model.

PUBLICATIONS RECEIVED.

Essentials of Engineering Mathematics, by J. P. Ballantine. 572 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1938. Price $3.75.

Electron Optics in Television, with theory and application of television cathode-ray tubes, by I. G. Malogg and D. W. Epstein. First Edition, 299 pages, illustrations, tables, 16 × 23 cms. New York, McGraw-Hill Book Company, Inc., 1938. Price $3.50.

Grimsehls Lehrbuch der Physik, neubearbeitet von Professor Dr. R. Tomaschek. Zweiter Band, Zweiter Teil, 456 pages, illustrations, 15 × 23 cms. Leipzig, B. G. Teubner, 1938. Price 10.50 R.M.

Photoelements and Their Application, by Dr. Bruno Lange, translated by Ancel St. John. 297 pages, illustrations, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1938. Price $5.50.

Sprinkle's Conversion Formulas, by Leland W. Sprinkle. 122 pages, 10 × 16 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1938. Price $1.25.

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CURRENT TOPICS

Congress Gets Report on Highway Accidents.—Measures recommended to reduce the highway accident toll are described in a report made to Congress by the Bureau of Public Roads of the U. S. Department of Agriculture. The report, based on extensive field studies, is published in six parts as House Document No. 462, Parts 1 to 6, and covers the following subjects: Part 1 presents a picture of the basic differences in traffic laws in the various states. Part 2 shows the dire need of analyzing accident causes in order to prevent future accidents, and the importance of studying physical aspects of a case before evidence is destroyed. The difficulties of investigating accidents immediately, particularly in rural areas, are outlined, together with a description of methods used by trained accident investigators. Part 3 pictures the variations and inadequacies of motor-vehicle accidents reporting throughout the United States. Of the 48 States, only 15 require accidents to be reported immediately to a central State agency, 19 have no central control, and 14 require no report. There is little consistency in the data called for by report forms and it is almost impossible to summarize the experience in those States requiring reports. Part 4, Official Inspection of Vehicles, deals with another phase of accident prevention. It is based on experience in the 15 States having State-wide, motor-vehicle periodic-inspection laws for all motor vehicles. Part 5 analyzes the case histories of 1,715 fatal highway accidents from the 1936 official records of representative States and cities. It shows the distribution of accidents by hour and by day, by type of accident and vehicle, by age, experience, and sex (women drivers were involved in only 6 percent of the accidents, but the percentage of women drivers and their mileage is unknown). The report also shows the causes of accidents whether by driver, passenger, pedestrian, or highway conditions. Drivers of borrowed cars are more likely to have accidents than owners, the report reveals, and the passenger has more chance of death than the driver. Part 6 discusses the accident-prone driver. The records on drivers kept by the department of motor vehicles of Connecticut were selected for study because of the carefully-kept card file which made it possible to check on accident repeaters. The 6-year record of every tenth name in this card file—a total of 29,531 drivers—was studied and compared. The study showed that in the general

population of drivers there is a small group that is definitely accident-prone and a much larger group that is just as definitely accident-free. Furthermore, according to the report, one can read the past and predict the future of these accident-repeaters. With this small but destructive group trained, disciplined, or removed from the highway, the accident total would be greatly decreased. These destroyers constitute only about 4 per cent. of the driver population but they cause 36 per cent. of the accidents. Other data verified the findings in the Connecticut survey. Another finding is that a driver is more likely to have an accident soon after being in an accident.

New Bar Stock Valves for Wide Application.—Three new bar stock valves which have uses in almost every industry are being introduced by Crane Co., Chicago. These small 3,000 pound W.O.G. plug type disc, globe and angle valves are called bar stock valves because their bodies and bonnets are made from solid bar stock. They are considered ideal for connections on orifice meters, regulator leads, by-passes, gauges, for use as expansion valves on ammonia line and for many similar services where accurate regulation of flow is desired or where parts of measuring instruments must be protected against the sudden release of high pressures. One kind, the Exelloy valves, are particularly suitable for handling oil or gas containing sulphur compounds or for installations where steel valves do not have sufficient resistance to atmospheric corrosion. Another, the 18-8 alloy valves, are especially suited for oil and gasoline containing hydrogen sulphide or sulphur dioxide when moisture is apt to be present. All of these valves may be packed when wide open when under pressure. They are furnished either in steel, Exelloy or 18-8 chrome nickel alloy.

R. H. O.

Official Weight is a Kilogram of Platinum.—According to the White Metal News Letter of the International Nickel Company a recent check-up of the American Standard Kilogram, the measure for all weights in this country, revealed that it has gained 18 one-thousandths of a gram over a period of forty-eight years or since 1889 when the kilogram, one of 82 in all, was manufactured by Johnson Mathey in London. For the check-up, our national kilogram was sent to France, where it was measured against a "use-copy" of the Perpetual Kilogram at the International Bureau of Weights and Measures at the Pavillion de Breteuil in Sevres. According to A. T. Pienkowsky, physicist at the National Bureau

of Standards in Washington, the change in the certified value of the standard is so small that considerations as to the possible cause are of very little value, the chief significance of the redetermination being that it shows a value practically identical with the former value, even for work of extremely high precision. Both weights are bars of 90 per cent. platinum and 10 per cent. iridium, as are the four "use-copies" which are kept for checking kilograms coming from all parts of the world, the platinum alloy having been chosen as the material least likely to shrink or expand, lose or gain weight. There is only one perpetual kilogram, the one which is conserved underground in Sevres. The safe in which it is placed has three locks, one kept by each of three prominent members of the International Bureau so that all three members holding the keys must be present whenever the safe is opened.

R. H. O.

Synthetic Resins are Developed for Airscrews.—*Industrial and Engineering Chemistry*, News Edition, Vol. 16, No. 4.) G. ABRAHAMSON reports from England that after extensive research in close collaboration with the Air Ministry, a new protective covering for wooden airscrews has been developed that is to take the place of the hitherto linen fabrics. The new covering consists of a fabric envelope treated with a special flexible synthetic resin of a rubbery nature that is pressed closely to the blades by a new hot molding process. This method provides a tough layer of protective material which is bonded very firmly all over the wood. Special reinforcement is incorporated in the covering along the edges, thus rendering metal sheaths superfluous. The new material is claimed to be superior to other protective covers in being unaffected by ultra-violet light, oils and gasoline. It is very resistant to moisture and general weather conditions, and offers effective protection to the wood.

R. H. O.

What Are the Uneconomic Uses of Petroleum.—In a recent paper before the A. I. M. E., JOHN D. GILL and E. J. KNIGHT of the Atlantic Refining Co. state that the objections concerning the alleged wasteful and uneconomic use of gaseous and liquid hydrocarbons are due to the belief that the supply is limited and that the functions they perform can be just as well performed by other resources like coal of which practically unlimited reserves are known. There are two types of critics; sincere advocates of the conservation of natural resources and the pseudo-conservationists with the ulterior motive of restricting the use of petroleum to further the

prosperity of other industries. That both are wrong is brought forth clearly. It is stated unequivocally that there are no uneconomic uses of petroleum. The resource is being employed as effectively as society, bulwarked by a highly developed technology, can feasibly employ it. Unquestionably during the last 25 years, the material welfare of our country has grown more rapidly than in any other period of equal length which was in large measure due to the use of gasoline for transportation. Picture the state of society were this fuel retarded either deliberately by planning or otherwise. From another angle, the competition which increasing quantities of fuel oil have opposed to the coal industries appears to have been a more potent force in increasing the operating efficiency of those industries than any other known economic factor. At the present time the petroleum industry has the largest proven reserve of its 80 years experience. Our country cannot afford to retard its peace time economic development by restricting the use of products which have proved themselves essential to that development. Technical developments are not lacking in the way of obtaining petroleum from coal, for instance, as a safeguard against the time, heralded by the conservationists, when the petroleum supply will be exhausted. The statement that there are no uneconomic uses for petroleum can therefore be supported by technical analysis as well as economic analysis.

R. H. O.

The Effect of Low Temperature on Properties of Metals.—VINCENT T. MALCOLM presented before the last annual meeting of the American Society of Refrigerating Engineers a very interesting paper on this subject which should appeal to many engaged in recently developed manufacturing processes such as dewaxing of petroleum, the handling of liquefied gases, and refrigeration. Various tests were described going down to as low as − 150 deg. F., on notched specimens using a 120 ft.-lb. Charpy machine of the Amsler type. It was stated that from the results of this work it is evident that the best type of material for extremely low temperatures is alloys of the solid solution type, wherein two or more elements that compare the alloy are so intimately associated with each other that even examination under a microscope fails to detect the different elements. High or medium carbon is not a desirable element in steels for low temperature service because it promotes embrittlement. The alloying elements found most useful in improving the properties of steel for low temperature service are the three soluble elements nickel, silicon and copper, as they tend to dissolve in iron producing material similar to solid solution alloys.

For cast materials either single or double normalizing followed by drawing gives best results. Care in manufacture to obtain clean, thoroughly killed steel is of importance. The copper-tin, copper-silicon, copper-zinc, and copper-nickel alloys do not embrittle at subzero temperatures.

R. H. O.

Aluminum Mountings for Aerial Survey Mosaics.—J. P. KOCH. (*Civil Engineering*, Vol. 8, No. 3.) Aluminum sheets are now used as a base for mounting aerial survey photographs in the Vicksburg District office of the Corps of Engineers, U. S. Army. They have been found easier to handle, more durable, and more economical than the pressboard mountings they replaced. Tests show that they resist extremes of heat, cold and moisture satisfactorily. The aluminum does not warp or cup and edges are not easily damaged. The size used is 27 by 40 in. of 20 gage sheet but it is believed that 18 gage might be more suitable. Twelve to fifteen aluminum-mounted mosaics occupy about the same space as four pressboard sheets.

R. H. O.

Forecasting Results of Atom Smashing.—In *Science News Letter*, Vol. 33, No. 10, there is a brief account of Prof. Vladimir Karapetoff's newly invented device which he exhibited before the Optical Society of America and the American Physical Society. The device can be set up on a table of elements to show the results of an impact upon any element or isotope by any one of several different kinds of sub-atomic "bullets" used in experiment. By properly using the scale the operator can read the theoretically possible resulting products of this atom smashing and the ejected particles that should come off.

R. H. O.

Hot Water Ice For a Skating Pond.—(*Public Works*, Vol. 69, No. 2.) Adjacent to one of the school buildings of Glencoe, Minn., is a public skating pond which was heavily patronized and quickly cut up. For smoothing the surface, water was flooded over it to freeze. This was done by using a dripping pipe about 15 ft. long, connected to the school building by a ¾ in. hose which is drawn across the ice. Flooding with cold water often produces a thin skimming of ice that shells off; but hot water was used in this case, which slightly melted the rough ice and fused with it, leaving a fine, smooth surface which did not shell off.

R. H. O.

Hydrogen Cooled Topping Unit Improves Station Efficiency.—(*Electric Light and Power*, Vol. 16, No. 3.) When the new 25,000 kw. topping turbine unit of the Millers Ford station of the Dayton Power and Light Co. started operation it became the first hydrogen cooled generator ever to go into service. An interesting feature of the turbine is that there are two casings, one within the other. The space between them is filled at the high pressure end with steam bled from the discharge of the seventh stage which at full load is approximately 400 lb. g. At the low pressure end the space is filled with exhaust steam. Some advantages of the double casing are lower stresses due to pressure differential, minimization of expansion and contraction stresses due to temperature differential, less heat loss through outer casing, and reduction of maximum pressure to which the shaft packing is subjected. The hydrogen cooled generator is rated at 25,000 kw., 12,000 volts, 0.8 power factor. Operating experience has shown a considerable decrease in temperature of the generator and a reduction of approximately 20 per cent in the no load steam input to the turbine due to hydrogen cooling. For the month of December 1937, 1320 cu. ft. of hydrogen were used in the generator. It is interesting to note that in 1936 the old low pressure plant had a heat rate of 19941 btu. per kw.-hr. send out. During the month of December 1937, the new high pressure unit was operating most of the time at reduced load due to lack of boiler capacity. In this month the heat rate was 17215 btu. per kw.-hr. send out for the combined high and low pressure plants. Under normal conditions, with the new high pressure unit operating at full load, it is expected to obtain a combined heat rate of 13850 btu. per kw.-hr. send out.

R. H. O.

Pennsylvania Fields Used to Store Coke Oven Gas.—(*Gas*, Vol. XIV, No. 3.) Storage of by-product coke oven gas in a natural gas field near McKeesport, Pa., has been successfully carried on by the Carnegie Natural Gas Co. since August 2, 1930. It is said to be the only instance in the world of a natural gas field being used for such storage purposes. As long ago as 1927 S. W. Meals, President of the gas company, suggested this method and he pointed out its economy over the usual method of gas holder storage. After making the necessary arrangements a 20 inch pipe line was constructed from the Clairton, Pa., by-product coke works of the Carnegie Steel Co. to the gas field. When the by-product coke gas was introduced into the field, it was found that the well pressure was raised one pound for every 10 million cu. ft. pumped in. The

largest quantity of gas stored in the field at any one time has been 600,000,000 cu. ft. Total pressure is ordinarily kept below 65 lbs. because of the risk of blowing out old wells that may not have been properly plugged. Originally, 25 wells were used to pump the by-product gas into the field, but operating efficiency has been improved by reducing the number to seven. The secret of successful storage of by-product gas in natural gas sands, according to Mr. Meals, is to keep it clean. Dust and tar, he points out, would seal the sand pores in the gas field, while sulphur in the gas would be likely to attack the steel in the pipe lines and tubing, and in time might have a tendency to clog the pore spaces in the sand. One of the greatest advantages of the storage field, and one not fully appreciated at the start, is that it enriches and adds to the gas that it holds. The pressure of the incoming by-product gas opens up new pockets of natural gas, and the natural gas comes up with the by-product gas when gas is taken out of the reservoir. From 1930 to 1937, 3,584,798,700 cu. ft. of gas was pumped in and 3,942,324,300 cu. ft. was withdrawn from the underground reservoir.

R. H. O.

Petrographic Identification of Atmospheric Dust Particles.—In estimating the hazardous qualities of a dusty atmosphere it is frequently desirable to determine the composition of the air borne dust. Samples collected from ledges or from rock itself are likely to be unsatisfactory for this purpose owing to the possibilities of differential disintegration of the rock and of variations in settling rates of the different components of the minerals. It may be necessary, therefore to collect samples of dust from the air. These may be analyzed chemically, by x-ray diffraction, and by the petrographic microscope. Chemical methods are unsatisfactory owing to the small samples usually available and to the limitations and complexities of present methods. X-ray technique requires expensive apparatus not ordinarily available except in research laboratories. Owing to the simplicity and rapidity of petrographic examination of atmospheric mineral dusts, the U. S. Bureau of Mines considered it worthy of further study. In its Report of Investigations No. 3368 by W. D. Foster and H. H. Schrenk a review is made of the use and limitations of the petrographic microscope and the method in use at present by the Health Division of the Bureau. A method has been worked out for determining a maximum value for the amount of quartz in a dust sample. The sample is studied under a microscope, using dark field illumination and immersing it in an oil with an index of refraction of 1.56. The material identified as similar to quartz may be anything from all

quartz to no quartz. This method may give a high value for quartz, but not a low one, and if none is found there is only a negligible quantity in the dust. This method may be modified to identify other minerals by using oils of other refractive indices, and the same limitations will hold.

R. H. O.

Human Aquarium.—(*Compressed Air*, Vol. 43, No. 3.) A so-called "human aquarium" has recently been built in France after the plans of J. L. Breton, director of the French National Office of Research and Invention. Designed for testing submarine equipment, it is also to be used for giving exhibitions of divers at work, of fancy swimming under water, and of marine life of all kinds. The structure consists of a basin, approximately 40 feet in diameter and 15 feet deep, the upper part of which is in the shape of a truncated octagonal pyramid having a base about 25 feet in diameter and sides sloping 45 degrees. The latter are made of plate glass and offer an unobstructed view of the interior of the tank from the surrounding spectators gallery. Immediately beneath the pyramidal section and built integrally with it is a pendant wall that extends down into the basin and forms an air pocket between it and the outer wall. This works on the same principle as the diving bell. As water flows into the tank and rises, the air trapped in this space is compressed, and when the air pressure and water pressure are equal the water is checked. This balance must of course be maintained; and this is done by admitting compressed air into the pocket as needed. Any excess air can be exhausted by way of a separate duct. The lower edge of the pendant wall is 4 feet 3 inches from the floor of the basin, and swimmers, or divers and other submarine workers without breathing apparatus, simply by ducking under this wall and putting their heads in the air pocket can fill their lungs with oxygen. The unsuspecting visitor, however, will probably wonder how the men can remain submerged as long as they do without apparently breathing. The water in the tank is heated for the comfort of the performers or workers and little difficulty is experienced in keeping it so because the tank is underground. An elaborate system of lighting has been installed. All wiring is carried in a new fireproof cable in which the dielectric is dehydrated magnesia. This remains dry throughout the life of the cable.

R. H. O.

Textile Fiber Derived from Milk.—(*Manufacturers Record*, Vol. CVII, No. 4.) The possibility of manufacturing on a commercial

scale in this country, a synthetic textile fiber comparable to that of wool, is no longer an anticipation of the chemical laboratory. For sometime such a fiber has been manufactured in Europe under license of an Italian company and attempts to sell the rights in this country have never been consummated due to a variety of reasons. However several patent applications have been filed including those of the U. S. Bureau of Dairy Industry. Should the Federal application be granted the formula will be available to manufacturers and the Southern states may offer possibilities for such production. The land retired from cotton growing may be put to no better purpose than the feeding of cows. Three acres of land will produce pasturage for a cow producing 4000 pounds of milk per year. From this can be obtained cream to make 190 pounds of butter. The skim milk will yield 100 pounds of casein which can be converted into 100 pounds of casein fiber. The whey remaining can be used as feed for hogs or calves. The production cost of casein fiber in this country should not exceed those of producing viscose rayon. In general, the process comprises the acidification of warm skim milk until the casein separates, firm the soft curd either by heating or by further increasing the acidity, wash, press, and dry the casein. Casein fiber is practically entirely casein, one pound of casein producing one pound of fiber. The modifying agents added in the manufacturing process add only a negligible quantity to its weight. It has an ultimate composition closely approximating that of wool, the chief difference being a less sulphur content. Because of this small sulphur content the material takes up much more color than does wool when dyed with acid colors in dilute acid baths. The fiber is faintly yellow in color, has a fine kink, and resembles in appearance a thoroughly washed and carded good Merino wool. Unlike wool fiber, which has a scaly surface, casein fiber is smooth.

R. H. O.

Air Conditioning Architecture.—(*Power Plant Engineering*, Vol. XLII, No. 4.) Air conditioning is so new that there has been little opportunity for architects to evolve designs which take full advantage of opportunities presented. For this reason the service building being built by the Detroit Edison Co. incorporating complete air conditioning is of unusual interest. Air conditioning and artificial light make it possible to utilize the full building area and increase the available floor area by eliminating light wells. Ground area is 248 ft. by 120 ft. and the building will be six stories in height. Incorporating the usual light wells in the design would have given

a gross floor area of 24 per cent. less and the perimeter 38 per cent. greater than the building to be constructed. Exterior walls will be of glass brick which is not appreciably more expensive than double windows and should have considerably lower maintenance. Winter heat loss through glass brick appears to be about equal to that of double sash windows and the infiltration should be negligible. Summer heat gain is said to be only about half of that through an unshaded factory type sash, although the area of glass brick is perhaps 30 per cent. greater than it would be for windows. The brick will not be shaded by awnings, whereas this would have been necessary with windows. The refractive pattern of glass brick picks up all external light regardless of the direction from which it comes and whether or not louver blinds or other glare dimming devices must be added later has not been determined. Heating and cooling have been combined in one system performed with a central fan. Backing tile in the exterior walls and much inside partitioning in the building will be constructed of a block developed by the company and made from fly ash collected from the pulverized fuel fired boilers. This ash is combined with lime and a little rosin and makes a serviceable well finished structural unit resembling concrete.

R. H. O.